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Fisheries Needs for Physical Oceanographic Information Within the Atlantic Zone

M. Sinclair, J.W. Loder, D. Gascon,
E.P. Horne, I. Perry, and E.J. Sandeman

Department of Fisheries and Oceans

August 1987

Issued by: Biological Sciences Branch
Scotia-Fundy Region
Halifax Fisheries Research Laboratory
Department of Fisheries and Oceans
Halifax, Nova Scotia B3J 2S7

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1568

Fisheries and Oceans / Pêches et Océans

Canada

88-02267/

Canadian Technical Report of Fisheries and Aquatic Sciences

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Canadian Technical Report of

Fisheries and Aquatic Sciences 1568

August 1987

FISHERIES NEEDS FOR PHYSICAL OCEANOGRAPHIC INFORMATION WITHIN THE ATLANTIC ZONE

by

M. Sinclair, J.W. Loder, D. Gascon, E.P. Horne, I. Perry, and E.J. Sandeman

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Department of Fisheries and Oceans
Halifax, Nova Scotia B3J 2S7

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Cat. No. Fs 97-6/1568E ISSN 0706-6457

Correct citation for this publication:

Sinclair, M., J.W. Loder, D. Gascon, E.P. Horne, I. Perry, and E.J. Sandeman. 1987. Fisheries needs for physical oceanographic information within the Atlantic Zone. Can. Tech. Rep. Fish. Aquat. Sci. 1568:viii + 166 p.

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ABSTRACT

Sinclair, M., J.W. Loder, D. Gascon, E.P. Horne, I. Perry, and E.J. Sandeman. 1987. Fisheries needs for physical oceanographic information within the Atlantic Zone. Can. Tech. Rep. Fish. Aquat. Sci. 1568:viii + 166 p.

A working group of fisheries biologists and physical oceanographers of the Department of Fisheries and Oceans was formed in May 1985 to determine fisheries needs for physical oceanographic information in the Atlantic Zone. This report summarizes their findings. A historical sketch summarizes the links between physical oceanography and fisheries biology in the northern Atlantic since the turn of the century. The review indicated that a critical requirement for the definition of fisheries needs for physical oceanographic information is a clear statement of the fisheries research questions themselves. Four categories of fisheries problems were identified: 1) definition of populations, 2) temporal changes in availability of fisheries resources to either commercial fisheries or research surveys, 3) causes of recruitment variability, and 4) long-term changes in abundance levels. The physical oceanographic information that is relevant to each of these categories of fisheries questions is discussed. Recommendations for research within the Department are provided.

RÉSUMÉ

Sinclair, M., J.W. Loder, D. Gascon, E.P. Horne, I. Perry, and E.J. Sandeman. 1987. Fisheries needs for physical oceanographic information within the Atlantic Zone. Can. Tech. Rep. Fish. Aquat. Sci. 1568:viii + 166 p.

Un groupe de travail composé de biologistes des pêches et d'océanographes physiciens du Ministère des Pêches et Océans a été établi en mai 1985 pour déterminer, du point de vue des pêches, ce dont on a besoin en ce qui a trait à l'information d'océanographie physique dans la zone Atlantique. Ce document présente leurs observations. Un bref aperçu historique illustre les liens entre l'océanographie physique et la biologie des pêches dans l'Atlantique nord depuis le début du siècle. La revue indique qu'un pré-requis important pour la définition des besoins des pêches en information d'océanographie physique est un énonçé clair des questions qu'on pose en recherches des pêches. On identifia quatre catégories de problèmes reliés aux pêches: 1) la définition des populations, 2) les changements temporels dans la disponibilité des ressources halieutiques tant à la pêche commerciale qu'aux inventaires de recherches, 3) les causes de la variabilité du recrutement, et 4) les changements à long terme dans les niveaux d'abundance. On discute de l'information d'océanographie physique propre à chacune des catégories de questions sur les pêches. Des recommandations pour de la recherche à l'intérieur du Ministère sont présentées.

CHAPTER 1. INTRODUCTION

In May 1985, the former Atlantic Research Directors' Committee (ARDC) of the Department of Fisheries and Oceans (DFO) formed a working group to determine fisheries and fisheries research needs for physical oceanographic information. It was named the "Working Group on Fisheries Oceanographic Requirements." The terms of reference were:

1. To define, within the context of the Atlantic Fisheries Service and OSS Atlantic, what physical oceanographic research and services are relevant to fisheries.

2. To identify and recommend to the Atlantic Research Directors' Committee the opportunities for new or modified oceanographic programs to meet the needs as defined under Term 1.

The Working Group initially reviewed a report on the same subject which was prepared within the old Fisheries Research Branch of the Scotia-Fundy Region (Sinclair et al. 1986a). This report provided perspective on diverse research questions associated with stock assessments and, as such, was a useful starting point, particularly for the physical oceanographers. In addition, a cursory historical review indicated that a critical requirement for the definition of fisheries needs for physical oceanographic information is a clear statement of the fisheries research questions themselves. This approach (i.e. initial definition of the fisheries research questions) was adopted by the Working Group. Four categories of fisheries problems were identified, and subsequently the relevant physical oceanographic information for each category was evaluated. These evaluations generated a series of conclusions and recommendations.

The report follows closely the temporal deliberations of the Working Group. The geographic area considered in the report, as well as the place names identified in the text, are shown in Figure 1. Chapter 2 summarizes the links between physical oceanography and fisheries biology in the northern Atlantic during this century. It is very much a sketch rather than a historical analysis. The key point is that there have been frequent attempts to link oceanographic research to fisheries problems dating from the turn of the century. Chapter 3 introduces the fisheries research questions considered to be of importance in the Atlantic Zone. Chapters 4 though 7 address the physical oceanographic information that is relevant to the four categories of fisheries research questions. The report is summarized and recommendations are listed in Chapter 8.

The approach taken by the Working Group (i.e. initial definition of fisheries research questions by biologists followed by evaluation of relevant physical oceanographic data and research predominantly by oceanographers) has perhaps led to a lack of emphasis on the need for multidisciplinary studies to make progress on many fisheries problems. The Working Group, at the end of their study, recognized this bias and wishes to stress the importance of joint work from the planning stages to completion of projects for certain problems. On the other hand, there are subject areas of great importance to fisheries for which joint work is not required. Throughout the report this distinction is pointed out. In addition, the emphasis of the Working Group

Fig. 1. Area map showing relevant topographic features.

has been on identifying relevant physical oceanographic research rather than on the organizational structure required for carrying it out. Subsequent deliberations on the recommendations could usefully further discuss the requirement for multidisciplinary approaches to specific problems. The research projects identified here are clearly not exclusive, and other topics may require more joint physics/biology research than those discussed here.

CHAPTER 2. HISTORICAL PERSPECTIVE

It is perhaps appropriate to provide a historical perspective on the linkages between physical oceanography and fisheries biology prior to addressing current requirements within the Atlantic Zone. It has long been recognized that oceanographic research is critical to fisheries problems. The importance of oceanography in this respect was stated, for example, in the first report of the International Council for the Exploration of the Sea (ICES) (1902), a council which in Sverdrup's words was,

> "...formed primarily for the purpose of applying oceanographic research to fisheries problems in the waters of northwestern Europe" (Sverdrup 1955, p. 287).

The history of the formation of ICES and the key role of physical oceanographic research in support of fisheries problems in the original mandate are described by Went (1972). A brief summary is provided here.

Stimulated by: 1) the recognition that overfishing was probably already occurring subsequent to the expansion of the trawling fleet as a result of the introduction of steam propulsion and the otter trawl in the latter half of the nineteenth century, and 2) the recognition that marine research was needed on large spatial/temporal scales to address the "overfishing" question, several European scientists began to promote the case for an international organization to deal specifically with the requirements of physical oceanographic research for fisheries. In 1895, O. Pettersson, a physical oceanographer from Sweden, made such a proposal at the Sixth International Geographical Congress in London. Three scientists - G. Ekman, O. Pettersson, and A. Wijkander - formally set out the conclusions of the London conference in a letter to the King of Sweden and in addition proposed an international study of the physical oceanography of the Arctic Ocean, the North Sea, and the Baltic, "...in the interest of fisheries." Partially as a result of their efforts, the first Conference International pour l'Exploration de la Mer was held in Stockholm in 1899. M. von Krusenstjerna, Minister of the Interior for Sweden, described the aim of the conference during his opening address in the following terms (note that the term "hydrography" meant "oceanography" at that time).

> "Le but de la Conférence est, comme vous le savez, de tâcher de créer une coopération entre les États du Nord de l'Europe pour des explorations hydrographiques et biologiques dans l'intérêt de l'industrie, si importante pour ces États, de la pêche maritime. Les explorations auront pour but de recherche la solution d'intéressantes questions scientifiques concernant un monde resté jusqu'ici peu connu. Mais, par

> suite de la connaissance que nous obtendrons de la manière de vivre des poissons et des conditions de leur existence, elles serviront en meme temps de directif pratique non seulement pour le développement, au point de vue économique, des pêcheries maritimes, mais aussi pour des accords internationaux tendant à ecarter l'emploi d'engins destructeurs."

Because of Pettersson's role in the stimulation of the conference itself, he was named secretary-general. Nansen, the renowned physical oceanographer from Norway, was one of the vice-presidents. A 5-yr research plan was proposed involving both hydrography (i.e. oceanography) and fisheries biology. The program, involving ten oceanographic components (or statements), was extensive (see Appendix 1). The linkages between the two programs, however, were not defined.

The second Conference International pour l'Exploration de la Mer, which was chaired by Nansen, was held in Kristiania in 1901. Additional proposals for oceanographic research included tidal studies, elaboration of "hydrographic tables" by Knudsen, and the use of hydrodynamic lines following the method of Bjerknes and Sandström. The provisional lines, along which some standard oceanographic observations were recommended to be made by member countries, are illustrated in Appendix 1. (Presumably, these are the so-called hydrodynamic lines; and some further discussion on their location and use took place at the second conference.)

The inaugural meeting of ICES itself was held the following year in Copenhagen. Physical oceanographers again played a major role. Pettersson was elected vice-president and Nansen the director of the so-called Central Laboratory established at Kristiania to service the oceanographic studies to be defined in support of the fisheries questions. Ekman was appointed as Nansen's assistant. The initial statements of the first Report of Administration of ICES dealt specifically with the interrelationships between scientific disciplines. It was stated that (p. 2, Volume 1 of Rapports et Procès-Verbaux des Reunions),

> "...it was seen from the beginning that the study of the physical conditions, of the chemical nature of the ocean waters, of the currents, etc., was of greatest importance for the investigation of the problems connected with life, that on the other hand, the study of floating organisms had particular worth for the solution of hydrographical [i.e. oceanographical] problems, and consequently that a sharp line should never be drawn between these two main divisions, yet nevertheless, were it only from practical considerations, one was obliged to think of this division of labour on account of the wide extent of the sphere of work."

The research program in physical oceanography that was outlined in the Stockholm and Kristiania meetings (see Appendix 1) was initiated immediately, the first international seasonal cruises starting in August 1902. Finland, Sweden, Denmark, Germany, Scotland, Norway, and Russia participated, carrying out standard activities in their respective areas of geographic responsibility.

To summarize, the statement by Sverdrup (1955) quoted above indicating that ICES was, "...formed primarily for the purpose of applying oceanographic research to fisheries problems...," although surprising given the present balance of activities within ICES, is perhaps not an overstatement. During the Jubilee year (25th anniversary) this conception of ICES was still extant. Maurice (1928), the president of ICES during the 25th anniversary year, states,

> "The function of the Council is so to coordinate the researchers of the nations adhering to it that each investigation may be an effective and necessary contribution to a well conceived and comprehensive programme of oceanographical research, and its ultimate aim is to furnish the knowledge essential to the rational exploitation of the sea" (emphasis added).

Throughout this relatively early period in the history of research in physical oceanography that was motivated by fisheries problems, the specific links to fisheries questions, however, are not obvious. Rather, the general impression received is that increases in understanding in the physical characteristics of the oceans, as well as in the circulation and mixing features, were considered to be relevant to fisheries questions. There was a spirit of exploration given that the oceans had not yet been adequately described. What is perhaps significant is that physical oceanographers, plankton specialists, and fisheries biologists participated frequently in the same committees such that the state-of-the-art questions in each discipline were well recognized by all participants. In retrospect, the increases in understanding during the first decade by the multidisciplinary ICES program must be considered remarkable.

This progress is well illustrated by the deliberations of the Council during its 12th Statutory Meeting held in Copenhagen, September 1913. It was in a certain sense a historic session. Johan Hjort presented a lecture on the evening of September 16 summarizing the Norwegian studies of Atlantic herring. Several generalizations were put forward which collectively merit the categorization of this time period (1902 to 1913) representing a paradigmatic shift in fisheries biology. The shift allowed much more precise fisheries questions to be addressed and, in principle, the linkages with physical oceanography to be more explicitly developed. Hjort's lecture and subsequent classic paper (Hjort 1914) comprised several key components. The general question he addressed was a major issue of concern to ICES, i.e. an explanation of the causes of the marked interannual variability in the quantity and quality of landings at different fishing areas in northern Europe. By quality, the size composition and relative composition of cod liver oil, for example, were of great commercial interest. The "mystery" underlying this empirical observation was to a large degree resolved in Hjort's lecture using herring as the primary example, and another set of questions (with which we are still grappling) was generated. The interannual variability in landings at a given location was convincingly demonstrated to be due to result from year-class variability of age-structured populations that are geographically persistent. It is this interpretation that is taken for granted today, but it took a decade of systematic international research by fisheries biologists to elucidate it. The hypothesis pointed the way for

future studies on recruitment variability. The paradigmatic shift involved the population as the unit of study rather than the species. This shift in fisheries biology predated the shift in taxonomic studies to "population thinking" by about two decades. Hjort, in addition to convincing most scientists that variability in landings was due in a large part to the very existence of age-structured populations characterized by variability in year-class strengths, argued that relative abundance was defined during the early life-history stages. He stated two hypotheses to address the recruitment variability question: the first involved the critical-period concept (i.e. food limitation for larvae), whilst the second stressed the variable role of currents in advecting the early life-history stages away from the appropriate distributional area for the population. The first hypothesis formed the basis for a detailed research proposal, at the 1913 meeting itself, for further work by the Council.

The proposal was put forward in the first instance by Professor Gran at the second sitting of the so-called "Plankton Section of the Council" the morning after Hjort's evening lecture. He stated (Appendix E, p. 124 of the 19th Rapport),

> "The fishery investigations indicate the probability, that the great periodical fluctuations in the fisheries are connected with the phenomenon, that the fish larvae only in some years are developed in great quantities.
>
> The Plankton Section desires to concentrate its work on the question, whether these fluctuations are correlated with differences in the plankton production in different years.
>
> It is proposed to begin an investigation, to be continued during several years, at the season when the larvae of the spring-spawning fishes develop.
>
> The plankton quantity should be investigated by means of water-bottles, centrifuge, and nets in connection with hydrographical investigations. Fish-eggs and larvae should as far as possible be examined in the living state, and the food of the larvae of various stages of development should be determined."

The proposal was received positively by the Plankton Section, albeit with caution. Professor Henking of Germany recommended the proposal,

> "...also on account of the fact that it would be a bridge between the fishery investigations on the one hand and the hydrography and planktology on the other. He would like to see the proposal so simple that it really could be carried out."

Pettersson suggested that the details of the research proposal should be discussed at a general meeting of the physical oceanographers and planktologists. This meeting was held the next day. The discussion focussed on the frequency and location of the sampling program. The plankton

observations were to be supplemented by standard hydrographic measurements at the fixed stations as well as on the transects. These joint deliberations, which effectively addressed the critical-period hypothesis of Hjort, formed the basis of a formal resolution (No. 15).

This joint meeting of the two sections (Plankton and Physical Oceanography) to explicitly address a fisheries question was the first direct linkage between the several disciplines. The Hydrography, Plankton, and Fishery Committees otherwise functioned to a large degree autonomously, even though certain individuals participated in several meetings.

The 1913 Statutory Meeting of ICES signalled the shift within fisheries biology from the purely descriptive mode to that of hypothesis testing. This in principle permitted the definition of specific research proposals in relation to fisheries questions rather than simply parallel work in a common geographic area of interest. Resolution 15 was an ambitious step in this direction. Unfortunately, the war which erupted the following year prevented the initiation of the joint study. In fact, no mention is made of the Resolution in subsequent meetings. The opportunity for well-defined cooperative studies on key fisheries questions was thus lost and was not picked up following the First World War. The reasons for this lack of continuity are not clear.

In 1951 ICES held a Special Scientific Meeting in Amsterdam to discuss the place of oceanography in fisheries research. In the introductory comments it was stated that the Meeting was stimulated in part by a paper which was presented at the 1950 Statutory Meeting by J. Carruthers and collaborators (subsequently published in Nature [Carruthers et al. 1951]) in which haddock recruitment in the North Sea was linked statistically to wind-generated physical oceanographic phenomena. There were other more-forceful factors, however, that led to the 1951 Special Scientific Meeting. Prior to the Second World War, in 1938, Hjort (as chairman of the Consultative Committee) proposed to the Hydrographical Committee that a subcommittee of oceanographers and fisheries biologists should be appointed to plan, "...combined hydrographical and biological investigations in future, especially with regard to the fluctuations of the conditions of life in the sea." The urgent need for improved collaborative work was generated by three quite specific events or problems. First, J.W. Sandström stressed the importance of studying the interannual variability of the Gulf Stream on both fishing and weather conditions in the northeastern Atlantic. Secondly, H.H. Gran suggested that the annual cycle of phytoplankton production in relation to oceanographic properties should be investigated in a comprehensive fashion on a broad geographic scale. Thirdly, J. Hjort felt strongly that the physical oceanographic and plankton surveys undertaken by ICES needed to be planned jointly to improve their potential usefulness for fisheries problems. His proposal to the Hydrographical Committee addressed these issues specifically.

The relevant documentation from the 1938 Statutory Meeting is reproduced in Appendix 2. A part of the proposal is also included here because it so clearly illustrates the hypotheses being considered at that time.

"An investigation of the annual period in the production of sea under the influence of the factors now known (the nutrient substances and the light) should be carried out for one individual year, special emphasis being laid on the above-mentioned area Shetland-Iceland. Subsequently, the results thus obtained will be capable of supplementation in connection with the hydrographic investigations, which are carried out four times a year, with the object in view of studying the correlations of the annual alternations in the marine currents and alternations from year to year in the production of the sea and eventually in the conditions for the numerical strength of the year-classes of important food fishes."

The point stressed here is that the somewhat haphazard oceanographic monitoring activities carried out by ICES member countries for fisheries purposes were not providing useable information. Hjort wanted the situation improved. As chairman of the Consultative Committee and president-elect of ICES, he was well placed to push his idea of a new Subcommittee on Combined Hydrographical and Biological Investigations. Just as in 1913 Hjort's aims of linking more closely physics and biology were stymied by war.

The Subcommittee was not set up until 1945. Their deliberations led to special oceanographic surveys (May and September) covering the North Sea, the Faroe-Shetland Channel, the southeastern Norwegian Sea, and the Skagerak (1947-1949). However, both the Hydrographical Committee members and other individuals doubted their utility. At the 1950 Statutory Meeting the role of physical oceanography in relation to biological problems was again a key agenda item of several committees. The Northern North Sea Committee dealt extensively with the influence of physical oceanographic and meteorological processes on recruitment variability. Two recommendations were made that are pertinent to this historical sketch,

"1. The Committee is impressed with the urgency of making hydrographical 'Standards' and 'anomalies' available to fisheries biologists as soon as possible. In particular the Committee is of the opinion, in relation to particular problems (spawning, larval development, etc.), that summarized wind data such as those submitted by Dr. Carruthers for the northern North Sea, and accumulated temperature data such as those submitted by Dr. Tait, can be of real value to biologists and others, and urges the Consultative Committee to request that these and similar relevant records (e.g. of sea currents) should be made available and maintained.

2. With such objects in view the Committee advocates that a Special Meeting in October 1951 should be held for the consideration of papers evaluating the effects of hydrographical features upon marine organisms, particularly commercial fishes."

In addition, there was some discussion both for and against the extant monitoring activities defined by ICES. The Hydrographical Committee also recommended the Special Meeting for 1951, and that annual charts of fish and plankton distributions as well as time series of year-class strengths, stock size, and egg production be prepared by the relevant Committees. These were to be analysed in relation to the time series of synoptic distributions of oceanographic and meteorological properties. The Hydrographical Committee meeting summary indicates that approaches to making oceanographic investigations more useful to biologists was a dominant theme. A memorandum by Graham and Lumby, "On steps to encourage fishery - hydrography" was presented. The Subcommittee for Organization of Combined Hydrographical-Biological Investigations deferred a decision on continuing the monitoring activities that had been carried out during each of the previous 3 yr. They also recommended that, "...monthly charts of surface temperature, surface salinity and surface phosphate distribution and also wind be prepared and circulated with the minimum delay to fishery-biologists." The Plankton Committee also recommended a Special Scientific Meeting. The Herring Committee recommended that, "A special committee should deal with the question of how a closer contact could best be reached between biologists and hydrographers in fisheries research." Finally the president of ICES, K.A. Anderson, presented a report, entitled "Co-operation Between Biologists and Hydrographers" to the Consultative Committee (reproduced in Appendix 3).

The diverse discussions in the various committees during the 1950 Statutory Meeting, as well as the recommendations themselves, had a major impact on oceanographic activities within ICES. The impact can be considered under two headings: the 1951 Special Scientific Meeting and its aftermath, and the ICES oceanographic survey activities. The Special Meeting is considered first.

The papers by Russell (1951 - "The Relation of Plankton Research to Fisheries Hydrography") and by Sverdrup (1951 - "Some Remarks on the Place of Hydrography in Fisheries Research") at the Amsterdam Special Meeting are pertinent to the mandate of the Working Group. Sverdrup's paper is very short, but he does make a few points of interest. His contribution was summarized by the chairman, C.E. Lucas, in the following terms.

> "Professor H.U. Sverdrup opened the session by giving the views of a professional hydrographer on the place of hydrography in fisheries investigations. Among other matters, he emphasized that it is the task of the biologist to demonstrate the reactions of the fish towards different types of environment. In the light of this knowledge the hydrographer should study the processes by which the environment is changed, as well as its momentary condition, so as to be in a position to forecast hydrographic situations of fisheries significance. In particular he made a plea for the hydrographer and the biologist to meet daily and to learn to write and speak so that each understand the other, as well as to disseminate their information speedily."

Sverdrup infers that fisheries biologists have to state clearly their research questions so that oceanographers can then study the relevant processes. This point led to the second recommendation of the Special Meeting (that the committees of ICES, "...should state as definitely as possible what problems they wish the hydrographers to attack and solve"). Sverdrup felt that there are two types of fisheries predictions with which oceanographers can help - the availability of fish, and the absolute abundance of the populations.

F.S. Russell (of the "Russell cycle" fame) makes essentially the same points in his "Introduction" section. He states,

> "...the success or failure of a fishery may be due either to changes in the habits and distribution of the fish themselves, or the fluctuations in the abundance of year-classes of the fish. In either instance the plankton may be a determining factor."

His presentation stresses the role of plankton dynamics on the generation of relative differences in year-class sizes of fish populations. His paper, at least in part, led to the sixth recommendation of the Special Meeting, that,

> "...the Plankton Committee [of ICES] should include (i) studies of the basic conditions of productivity in the sea, and (ii) an attempt, by observations over a series of years, to correlate the number of survivors of a year-class of fish with the presence or absence of any one or more types of plankton organisms, both predatory or food producing, during the early planktonic life of the fish."

This is in essence a restatement of Gran's 1913 proposal. Another recommendation of interest was also generated by the Russell and Sverdrup presentations. Recommendation 5 states,

> "...as a direct means of showing the dependence of the fish stocks on hydrographic [oceanographic] conditions, and as a direct help to the fisheries, experimental fishing on a commercial scale and other forms of assessment should be carried out simultaneously with hydrographic [oceanographic] observations."

All three of the above-quoted recommendations of the 1951 Fisheries Hydrography Special Meeting are germane a quarter of a century later (the full set of recommendations is listed in Appendix 4). Their Recommendation 4 is also in essence repeated by our Working Group. It states that,

> "... efforts should be made to encourage the writing of monographs describing the hydrographic (i.e. oceanographic) conditions in the seas in which fishery workers are interested."

Lee (1984, p. 15/16) summarizes the degree to which the recommendations were met in the intervening years. He feels that the problem of communication between the two disciplines has continued to be a "thorny one," fish distributions have not been related to oceanographic features, and monographs on the oceanography of important fishing areas have not been systematically generated. Annual summaries of oceanographic conditions in the northeastern Atlantic, however, have been made available routinely to fisheries biologists in Annales Biologiques since 1939. Given the clear concern by ICES as a whole on the issue of oceanography in support of fisheries at the 1950 Statutory Meeting, the activities by both disciplines in the intervening years have been modest at best.

Lee (1984, p. 11/13) also summarizes the oceanographic survey activities and their application to fisheries problems within ICES that arose following the 1950 Statutory Meeting. It is a most useful summary of the difficulties of sustaining oceanographic monitoring programs. The extensive May and September synoptic surveys carried out in 1947 to 1949 were never fully analysed and published. It may be noteworthy in this respect that Hjort, the dominant influence on this study, died in 1948. Several monitoring initiatives followed, based to a large degree on ships of opportunity. The data products, however, were rarely used by fisheries biologists.

The oceanographic monitoring programs for fisheries in the northeastern Atlantic are summarized below.

1902-1914	Quarterly cruises specifically designed by ICES; data products rapidly published.
1926-1928	Oceanographic data collected on an opportunistic basis; published quickly in the Bulletin Hydrographic Trimestriel.
1947-1949	May, September synoptic cruises over large area; never fully published.
1950-1952	Ships of opportunity monthly synoptic charts of seas around the British Isles; published by Lowestoft (including temperature, salinity, wind and current data).
1952-1960	Same service as 1950-1952 by Lowestoft provided by the Service Hydrographique of ICES.
1957	Current data dropped from monthly synoptic charts.
1961	Total program of monthly synoptic charts discontinued.
1966	Proposal for a permanent ICES centre for synoptic fishery oceanography; not acted on.
1971	Monthly charts on bottom-layer temperature and salinity in selected areas produced by the Service Hydrographique.

Since the early 1970's interest in using remote sensing data to generate customized data products has been evaluated by the renamed Hydrography Committee (previously called the Hydrographical Committee). There is, however, at present no oceanographic monitoring program for fisheries questions within ICES. The issue of time series of data products, however, was on the agenda of the 1986 meeting of the Consultative Committee.

The failure to fully analyse the oceanographic data in the ICES area and make it available to the fisheries biologists in an interpreted form has had a negative impact. Lee (1984, p. 12) states,

> "...that erroneous ideas concerning the current system of the North Sea were allowed to persist for a long time, especially among biologists. Charts of this were being used until 1980 which were based on drift-bottle experiments, the value of which was considerably diminished because no account was taken of the influence of wind on surface drifters..."

For further details on the more recent activities of the Hydrography Committee, the Lee paper is most useful.

Closer to home, in the Northwest Atlantic Fisheries Organization (NAFO) area, there have also been several substantive initiatives to link oceanographic properties and processes to fisheries problems. Fisheries oceanographic initiatives were dealt with on an ongoing basis by the Environmental Studies Subcommittee of ICNAF. In addition, there have been a number of symposia dealing specifically with fisheries oceanography in the area of the Convention.

Early in the history of the International Commission on Northwest Atlantic Fisheries (ICNAF) there was clear interest in the role of oceanographic research in support of fisheries management questions. During the second annual meeting in July 1952, two thrusts demonstrated this. A Hydrographic Subcommittee of the Standing Committee on Research and Statistics was formed and the Executive Secretary of ICNAF was charged with arranging, during the 1953 annual meeting,

> "...a symposium on long-term changes in hydrographic conditions and corresponding changes in abundance of fish stocks to guide us in planning hydrographic programs and to throw light on the effects of such natural factors on fisheries."

Thus, the special ICNAF meeting on Long-Term Hydrographic Changes and Their Effects on Fish Stocks in the Northwest Atlantic was convened in June 1953 (published in ICNAF Annual Proceedings, Vol. 3, pt. 5:67-86). This meeting was followed by a landmark paper, "The Waters of the ICNAF Convention Area," prepared by Hachey et al. (1954) especially for the ICNAF scientists.

The need for close ties between oceanography and fisheries research emerged as a continuing theme both in ICNAF statements of research needs and in the research programs of the member countries that are coordinated through the ICNAF forum. A working party was convened in 1961 under the chairmanship

of C.E. Lucas to address this research area. Specifically, ICNAF had requested advice on:

1. The effects of the environment on the survival of eggs and larvae, growth, long-term abundance and distribution of cod in particular, but also of redfish and haddock.

2. How studies of such matters might be directed so as to not only provide evidence of associations but also lead to prediction.

3. What fundamental studies requisite for such investigations and not already proceeding should be initiated.

4. How plans could best be laid for holding an Environmental Symposium.

The report of the Working Party was presented to ICNAF at the Woods Hole meeting in 1961 and accepted essentially in total (p. 61-89 of ICNAF Redbook for 1961). The report both laid the foundation for the first environmental symposium (Rome 1964) as well as generated a large-scale international research project on the early life-history stages of commercially important species in Areas 1 and 2 in relation to oceanographic processes (NORTHWESTLANT). The program and its results are documented in the massive ICNAF Special Publication No. 7. In retrospect the significance of this first major "big science" effort on fisheries oceanography does not justify the efforts expended. This program was the forerunner of the Georges Bank herring and Flemish Cap cod recruitment studies conducted under the auspices of ICNAF/NAFO. These latter studies are looked at in more detail in Chapter 6 in relation to recruitment research.

As stated above, the first of the symposia on environmental issues in relation to fisheries in the northwestern Atlantic took place in 1964 in Rome. As Lucas was chairman of both this first ICNAF Environmental Symposium and the 1951 ICES Symposium on Fisheries Hydrography at Amsterdam, he was well placed to provide the perspective on increases in understanding. It was a state-of-the-art symposium involving invited review papers, nine section summaries, and the papers themselves (ICNAF Special Publication No. 6, 1965). He concludes (p. 2) that even though considerably more work had been carried out on the physiology of fish in the intervening years (i.e. between 1951 and 1964),

> "It may also be fair to suggest that some of the lessons of that 1951 symposium have still to be fully digested."

Lucas stressed the importance of a balance between process-oriented studies in physical oceanography and long-term broad-scale monitoring. Ongoing communication between disciplines and joint research planning were again encouraged. In a certain sense the meeting reinforced the recommendations of the 1951 Special Meeting. There was a clear link between the two symposia with frequent cross-referencing. The formal recommendations of the 1964 Symposium were presented to the ICNAF Subcommittee on Environmental Studies (see Appendix 5 for relevant extracts). Recommendations 33 and 34 are of particular interest in that they deal with the need for increased monitoring

of physical oceanographic properties as well as descriptions of circulation in offshore fishing areas.

Other contributions to the ICNAF oceanographic program include a Special Meeting in May 1967 on fluctuations in sea and air temperatures from 1950 to 1966 in the ICNAF convention area (ICNAF Redbook 1967, Pt. IV). Two additional symposia were held on fisheries oceanography to review respectively conditions during the decades of the 1960's and 1970's (ICNAF Special Publication No. 8 [1972] and NAFO Scientific Council Studies No. 5 [1982]). Finally, other meetings pertinent to this sketch include the Special Session on Ice and the Symposium on Unusual Environmental Conditions in the Newfoundland Grand Bank area in 1972 (ICNAF Special Publication No. 9 and 10).

It would appear that ICNAF, and more recently NAFO, has more actively reviewed oceanographic conditions than has ICES in recent years. In general, however, the papers presented during the more recent decadal overviews have not considered fish and physics together. Notable exceptions are Templeman (1972), Bernstein and Mann (1982), and Sergeant (1982). The 1964 symposium, in contrast, deals extensively with interactions, in particular in Sections A and H.

Within ICNAF there have thus been two categories of activities linking physical oceanography to fisheries: 1) the environmental symposia series, and 2) major international recruitment-related research programs (NORTHWESTLANT, Georges Bank herring, Flemish Cap cod/redfish). The Government of Canada has also reviewed the linkages between physical oceanography and fisheries within the northwestern Atlantic. In 1964, representatives of the Fisheries Research Board of Canada (FRB) and the Department of Mines and Technical Surveys (DM&TS) (which at that time had primary responsibility for physical oceanographic studies) met to discuss, among other issues, their respective responsibilities in biological and physical oceanography (the Atlantic Fisheries Oceanography Meeting). Much of the discussion involved the need for monitoring of physical oceanographic properties. The FRB was willing to discontinue their efforts in this field if the DM&TS would take it over. The matter of how best to carry out an effective program, meeting fisheries needs, was discussed at some length. The FRB was asked to indicate specific requirements and indicate their priorities.

> "It was agreed that FRB would consider what its needs were in oceanographic monitoring and would submit these to DM&TS as soon as possible, indicating priorities in each. It was further agreed that DM&TS will gradually take over the oceanographic monitoring presently handled by FRB, when personnel become available. It was agreed that the monitoring should be intensified at the earliest possible moment."

The summary of the Meeting indicates the concensus that extensive physical oceanographic studies were required for fisheries problems and,

> "DM&TS are prepared to carry out non-biological marine studies (research and surveys) in response to FRB needs and are prepared to go to considerable length to meet specific fisheries needs."

The physical oceanograhic community did not, however, take over the monitoring program; and links with fisheries research were not developed on a sustained manner. The reasons for the lack of follow-up from the first Atlantic Fisheries Oceanography Meeting in 1964 are not evident to the Working Group. FRB did review their requirements and priorities (see Appendix 6).

Several points can be gleaned from the preceding somewhat selective review of how physical oceanographic research has been linked to fisheries questions within ICES and ICNAF/NAFO between 1902 and the present.

1. It has been recognized (since at least the turn of the century) that physical oceanography is critical to fisheries questions.

2. Physical oceanographers played a major role in establishing ICES, with a specific mandate to facilitate appropriate oceanographic research to resolve fisheries questions. Oceanographers of high caliber (Pettersson, Nansen, Ekman, and Sverdrup) were actively involved in the definition of the research questions and associated programs.

3. Oceanographic research programs directed towards specific fisheries questions, however, have not been common, even though precise hypotheses on fisheries questions have been stated since 1913.

4. Even within a common organizational structure, oceanographic and fisheries work have generally been treated separately.

5. The underlying premise, although unstated, seems to have been that parallel research on respectively oceanographic and fisheries state-of-the-art questions will result in increases in understanding of the role of oceanographic processes on diverse aspects of fish biology.

6. Communication between oceanographers and fisheries biologists was much more pronounced during the early period (1902 to 1951) than is generally the case today. Oceanographers participated in the committee discussions involving fisheries questions and vice versa.

7. A major international multidisciplinary initiative to test Hjort's critical-period hypothesis on recruitment variability was interrupted by the First World War. Nothing so ambitious has subsequently been carried out. The reasons for the lack of joint oceanographic/fisheries research on Hjort's two hypotheses until recent years are not obvious.

8. The requirement for increased monitoring of oceanographic properties in in relation to long-term trends in resources has been repeatedly discussed throughout this century both within ICES and ICNAF/NAFO. Fisheries biologists, however, have rarely used the oceanographic data products when they have been produced. Further, institutional support

for extensive monitoring programs has not been sufficient to sustain diverse initiatives within ICES.

9. Big science initiatives in fisheries oceanography have in general been disappointing for a variety of apparently different reasons (1913 and 1938 "Hjort" programs because of war, 1947-49 project as a result of Hjorts death[?], 1963 NORTHWESTLANT for undefined reasons).

10. The 1951 Special Scientific Meeting of ICES specifically addressed the place of oceanography in fisheries research. The recommendations of that Meeting (see Appendix 4) are relevant today.

Recommendation 2 of the 1951 Meeting, which was stimulated in part by Sverdrup's presentation, forms the first step in the Working Group's approach to meeting its terms of reference. In the following section the important fisheries questions are defined. The historical perspective suggests that the hopes of the physical oceanographers who stimulated the formation of ICES have not been fully realized. In spite of the enormous increase in sophistication within physical oceanography and in the understanding of the physics of the oceans between 1902 and the present, there are few examples in which physical oceanography has been successfully directed towards the resolution of specific fisheries questions. No doubt there are fundamental reasons for the gap between early expectations and achievements to date. It was certainly not, at least in the early years, due to a lack of interest or commitment by the physical oceanographic community. There have been several ambitious attempts to integrate the two disciplines to better address fisheries problems (1913, 1938, and 1950 at the ICES Statutory Meetings and their follow-up actions; 1961 at the ICNAF Scientific Meeting and its follow-up research and environmental symposia). Part of the difficulty may have been the inability given the respective states of the art in oceanography and fisheries biology to define joint tractable questions. Initially, the fisheries questions (as stated in 1913, for example) were perhaps too sophisticated for physical oceanography; that may not be the case today. The main thrust in physical oceanography quickly became an investigation of the large-scale mean circulation of the deep ocean, with limited emphasis on the variability in continental shelf processes (Wunsch 1981); that trend was not significantly reversed until the 1960's. In this sense the present may well be fruitful for a reconsideration of the role of physical oceanography in fisheries research.

CHAPTER 3. FISHERIES RESEARCH QUESTIONS OF IMPORTANCE IN THE ATLANTIC ZONE

Following the recommendation generated by Sverdrup's presentation at the 1951 Special Scientific Meeting (i.e. that fisheries biologists need to state clearly the critical research questions), a two-step work plan has been adopted for this Working Group. The "fisheries" members of the Working Group were asked to provide the critical research questions facing fisheries management in their respective regions. Each core member of the several Canadian Atlantic Fisheries Advisory Committee (CAFSAC) subcommittees was also asked to provide input. These research questions formed the basis of the subsequent definition of requirements for physical oceanographic information in support of fisheries research.

Most of the fisheries research questions requiring physical oceanographic support could be grouped into four categories: 1) definition of populations, 2) temporal changes in availability of fisheries resources to either commercial fisheries or research surveys, 3) causes of recruitment variability, and 4) long-term changes in abundance level. Each of these four categories is briefly discussed below.

3.1. DEFINITION OF POPULATIONS

An understanding of the distributional patterns of populations (or stocks) within the geographic range of commercially important species is important to the definition of the component management units (Heincke 1898; Redeke 1912; Hjort 1945; Iles and Sinclair 1982; Sinclair and Iles 1985). For invertebrate species in particular, but also for some fish species, an understanding of these patterns is the most critical question facing fisheries management in the Atlantic Zone. Without an understanding of the geographic extent of the diverse populations the source of recruitment cannot be understood. This research question was considered by the relevant specialists to be critical to the management of sea scallop, Icelandic scallop, lobster, shrimp, snow crab, short-finned squid, Gulf of St. Lawrence herring, and Greenland halibut. The Working Group considered that, in general, a tight coupling between disciplines was not necessarily required at this time in relation to this fundamental research question. To aid in addressing the "population question," fisheries biologists require descriptions of the general mean circulation patterns and their seasonal variability over the relevant continental shelf area (Labrador Shelf to Mid-Atlantic Bight). In addition, large-scale descriptions of average seasonal patterns in the temperature and salinity characteristics of the same area are considered to be useful. A summary analysis of the availability of this sort of descriptive information on the physical oceanography of the east coast continental shelf area from Cape Chidley to Cape Cod is provided in Chapter 4 of this report.

3.2. CHANGES IN AVAILABILITY

The second category of fisheries research questions involves temporal changes in availability of fisheries resources to either commercial fisheries or research surveys. This problem, and its relevance to Atlantic Zone fisheries management issues, has been forcefully and clearly stated by Pinhorn and Halliday (1985). The biological problem is that there are marked interannual changes in availability of fish and invertebrate resources to various segments of a fishery (in particular to the fixed-gear components, but not exclusively) and to the research surveys resulting from changes in spatial distributions (not from changes in abundance of the population in a management unit). It has been inferred in many cases that shifts in availability of commercially important resources are caused by variability in the physical oceanographic environment, particularly in water temperature. Two examples of availability shifts are addressed in some detail in Chapter 5 of this report - northern cod availability to the Newfoundland/Labrador inshore fishery and silver hake spring/summer migration onto the Scotian Shelf. Several other examples of availability problems within Atlantic

fisheries were identified by the Working Group. Each case could benefit from a detailed analysis of the type provided for northern cod and silver hake. The cases that are not further evaluated are briefly described here.

Shrimp abundance in the northwestern Gulf of St. Lawrence, and undoubtedly in other areas, is difficult to estimate using present survey methodology. It is thought that at least part of the problem in the accuracy of the survey estimates results from changes in the availability of shrimp. The degree to which oceanographic changes influence shrimp behavior and distribution, and thus availability to the survey, is not known. The Working Group noted that there is a large data set on interannual variability in temperature and salinity in this area of the Gulf of St. Lawrence. Thus, further work in relation to the availability question might be fruitful.

A second example was also from the Gulf of St. Lawrence. The timing of migration of herring from their deeper-water overwintering areas to diverse spawning locations within the coastal zone of the western Gulf has been shown to be a function of temperature. The complete oceanographic data set, however, has not been used. The present hypothesis by S. Messieh involves interannual fluctuations in the depth of the temperature minimum layer. Again it was felt by the Working Group that further exploratory analysis of the accummulated data sets on oceanographic properties in the southern Gulf of St. Lawrence and herring spawning times could be profitable.

A third example is the interannual changes in distribution of cod on either side of the Laurentian Channel in the Cabot Strait area (Sinclair 1983). The studies on the long-term temperature variability in the Gulf of St. Lawrence by AOL may be useful in interpreting the observed changes in cod distribution.

A final example of a potential availability problem in Atlantic Canadian fisheries is American plaice on the Grand Banks (based on dramatic decreases in catch rates during the 1986 fishery, coincident with modest changes in the survey index of abundance). The Working Group did not feel in this example that the biological information was sufficient to merit further investigation of the associated physical oceanographic process that may be involved in the change in availability.

In contrast to the first category of fisheries questions coordinated, jointly planned multidisciplinary research programs are required for this category of fisheries problems. Preferably the research programs on availability changes should comprise self-contained disciplinary components (jointly planned) so that a physical oceanographic component would still yield useful information (e.g. for other applications) if the fisheries component were to be unsuccessful.

3.3. RECRUITMENT VARIABILITY

The third category of fisheries research questions concerns the thorny issue of the causes of recruitment variability. Within the Atlantic Zone three major projects that fall within this category are near completion: the Georges Bank herring study, the Flemish Cap redfish/cod study, and the Browns

Bank haddock study. In each case there was a substantive contribution by physical oceanographers within the Department. These studies, however, have not been fully evaluated with respect to their stated aims. In particular, it is not yet clear if the physical oceanographic contribution was adequate for the biological question being addressed. For the latter program (Browns Bank haddock) it may in fact be premature to attempt such an evaluation as the study is not yet complete. The Georges Bank and Flemish Cap recruitment studies, however, were the subject of a Special Scientific Meeting of NAFO held in September 1986. The Working Group adopted a dual approach towards an analysis of this third category of fisheries research questions. First, the physical oceanographic input to the above three major recruitment variability programs is described. In addition, the results of the NAFO Special Scientific Meeting are evaluated in relation to the adequacy of the physical oceanographic component of the projects. Secondly, a statement on the Working Group's position on the approach to be taken toward recruitment studies is formulated. This section includes Atlantic Canada's potential involvement in the International Recruitment Project (IREP), as well as opportunities for recruitment-related research on invertebrates. Magdalen Islands lobster is highlighted because of the predictive power of the freshwater runoff index (RIVSUM) for lobster yield in this area (Sutcliffe 1972; 1973; Sheldon et al. 1982; Drinkwater 1987; Sinclair et al. 1986b). The causal mechanisms underlying the correlation are not understood and have not been aggressively investigated. Also, the potential study involves an invertebrate resource. Invertebrates have not been addressed in previous major recruitment studies. The two analyses of the physical oceanographic needs for this third category of fisheries questions are presented in Chapter 6 of this report. Again, the Working Group perceives jointly planned multidisciplinary research programs with self-contained disciplinary components to generally be most appropriate to this category of research questions.

3.4. LONG-TERM CHANGES IN ABUNDANCE LEVELS

The final category of fishery research questions involves the possible influences of interannual variability in the physical environment of coastal and continental shelf waters to long-term changes in abundance levels. Marked changes in fisheries yields and geographic extent of distributions are observed on a decadal time scale. A recent example which has had a dramatic impact on the fishing industry is the change in recruitment levels (not the interannual variability, but rather a shift to a lower-characteristic absolute abundance) for Labrador cod. Medium-term projections of abundance based on the recent history of the management unit have turned out to be serious overestimates. It is not interpreted that overfishing is the causal factor. A second example is the low-frequency shifts in sea urchin abundance along the coast of Nova Scotia, which may have an influence on productivity of the coastal zone. Examples of long-term changes in abundance levels in the northeastern Atlantic include the Plymouth herring and the pilchard landings in the English Channel area (Cushing 1961; Wyatt 1984). In general terms, based on the commercial fisheries catch and effort statistics, as well as the standard research vessel surveys, a systematic description of the variability in certain biological parameters on a decadal time frame is becoming available (i.e. species composition and relative abundance from the

standard groundfish research vessel surveys; see Mahon et al. 1984 for a description of the data base). In contrast, the data base for physical oceanographic properties is being archived on an opportunistic basis. In Chapter 7 of this report an analysis of the requirements for monitoring of physical oceanographic properties is presented. Parallel research programs in fisheries and physical oceanography should be adequate after the disciplines have jointly determined appropriate oceanographic properties to monitor.

3.5. A GENERIC PROBLEM

During the discussion of the fisheries research questions a generic problem surfaced that no doubt hinders development of fruitful linkages between the two disciplines. The biological questions, as a rule, are not sufficiently well stated to permit detailed research project planning by a joint team of physical oceanographers and biologists. Details are required. Frequently the fisheries question is perceived in general terms, but there is not sufficient detail presented (or perhaps even available) to permit development of the plausible linkages with oceanographic phenomena. A notable exception is the background documentation for the northern cod availability problem. The documentation in this particular case facilitated an analysis of potential physical oceanographic requirements. It is this level of documentation on a case-by-case basis that is required for meaningful definition of research initiatives in associated disciplines.

CHAPTER 4. SUMMARY OF CIRCULATION AND TEMPERATURE-SALINITY INFORMATION FROM THE ATLANTIC CANADIAN SHELF

4.1. INTRODUCTION AND APPROACH

4.1.1. Relevant Time and Space Scales

The starting point for any discussion of circulation and temperature and salinity distributions must be the determination and/or specification of the time and space scales that are of interest to the questions at hand.

The time scales implicit in the first category of fisheries research questions are the long-term mean and seasonal variations of the distributions of current, temperature, and salinity on the Atlantic Canadian shelf. The accumulated observational information from the region, however, indicates that the currents and water mass properties fluctuate on a broad range of time scales. This range extends from periods of the order of 1 min and 1 d for internal wave and tidal motions respectively, through periods of the order of 1 wk and 1 mo for motions forced by wind events and deep-ocean eddies respectively, to the seasonal and interannual variability associated with the solar cycle and longer-term fluctuations in the atmosphere-ocean-cryosphere system. This broad spectrum of variability has significant implications for the specified fisheries requirement. First, the relatively high-frequency variability must be considered in any sampling scheme in order to avoid obtaining spurious lower-frequency variations resulting from aliasing. Secondly, the measured mean value of any physical property, such

as the so-called residual circulation, may depend on the length of the measurement period unless that period is long enough to resolve all of the energetic variations. This generally requires that the measurements be of at least 1 yr's duration so as to resolve any seasonal cycle, although seasonal means may be obtained from appropriate records of shorter duration. If there is strong interannual variability, however, measurements of many years' duration may be necessary, in which case the required physical oceanographic measurements merge with the monitoring programs required by the fourth category of fisheries questions. Finally, and perhaps most importantly, the "fisheries significance" of the mean and any seasonal variation in the physical environment may also be critically dependent on the magnitude of the higher-frequency variations. The seasonal and long-term means of currents, for example, must be considered in relation to the standard deviation of all higher-frequency current fluctuations occurring on time scales of relevance to the particular fisheries problem. Similarly, seasonal variations must be considered in relation to appropriate statistical measures of both interannual and higher-frequency variability. Considering these implications of the observed broad spectrum of variability in current, temperature, and salinity, further specification of the requirements of the fisheries research problems is required. The discussion in this chapter will be largely limited to the availability of relevant data for a seasonal description, while an examination of the adequacy of this data base must await further elaboration of the fisheries problems.

The space scales of the distributions of current, temperature, and salinity on the Atlantic Canadian shelf have, in general, not rigorously been determined. However, the accumulated observational and theoretical information indicates that the seasonal and mean circulation patterns and distributions of temperature and salinity in the region include at least three horizontal space scales. Because the entire shelf area between Cape Chidley and Cape Cod is influenced by the along-shelf, Equatorward flow of the Labrador Current and the St. Lawrence River outflow, the circulation and temperature and salinity distributions can be discussed on the "broad" scale of the latitudinal extent of the entire area and the shelf width. This scale is of the order of 2,000 km in the along-shelf direction and 200 km in the cross-shelf direction.

The second horizontal space scale over which significant current and water mass property variations have been observed, and which may be of particular significance to the first category of fisheries questions, is the "topographic" scale corresponding roughly to the horizontal extent of banks, embayments, troughs, saddles, channels, and straits. In the following discussion, topographic features with scale of the order of 100 km and greater will be considered.

The third significant horizontal space scale is a dynamical one - the internal Rossby radius of deformation. This is the natural horizontal scale over which adjustment to density and topographic changes occurs in a rotating stratified ocean, essentially forming a high wavenumber cut-off for seasonal and lower-frequency patterns. For typical conditions on the Atlantic Canadian shelf in summer when this scale is most significant, as well as smallest, it is of the order of 10 km. Variations on this scale will not be dealt with explicitly here, but it may be considered to be the minimum scale for the occurrence of water mass property variations (i.e. frontal zones)

between topographic regimes and the minimum width of baroclinic "jet-like" currents occurring along the shelf break and the perimeter of topographic features. This internal deformation radius is also the width of the zone adjacent to coastlines that is most strongly influenced by runoff and wind-driven upwelling.

In addition, variability of the currents, temperature, and salinity on the vertical space scale must be considered. In general, the currents on the Atlantic Canadian shelf are known to include both barotropic (independent of vertical position) and baroclinic (vertically structured) components, while the temperature and salinity profiles typically include surface and bottom mixed layers and an intervening region of large vertical gradient (the thermocline or halocline). In contrast to the horizontal structure, however, the vertical structure is usually resolved in conventional physical oceanographic measurement strategies.

4.1.2. Quantity of Available Data - Currents

The primary data base for a statistical description of current patterns and their variability in the region is the set of Eulerian observations obtained from moored current measurements. Figure 2 shows the number of months of current meter data archived as of July 1986 at the Atlantic Oceanographic Laboratory (AOL) for the various 1° squares in the region (courtesy of D. Gregory, Coastal Oceanography Division, AOL). The number of current meter months was obtained by summing the lengths of record (in days) from all instruments at all depths in all seasons in each square, dividing by 30 (days/month), and truncating. The archives include some of the current meter observations obtained by industry and other institutions but do not include some recent AOL observations. The summary figure, however, does form a useful basis for discussion of the regional distribution of available data and of the extent to which the fisheries requirement for a description of seasonal current patterns can be met.

It is immediately clear that the spatial coverage of existing moored current measurements is incomplete; there are no records in the archives for large areas of the shelf. The length and number of records required to resolve the seasonal variation of circulation pattern will vary with location, depending on such *a priori* unknown factors as the horizontal and vertical scales of variation and the relative magnitudes of the seasonal, interannual, and higher-frequency variability noted above. As a rough yardstick for discussing the adequacy of available data for the fisheries requirement, it is probable that at least two years of observations at each of two vertical positions would be required to provide a first approximation of the description of the current's seasonal variability and some indication of its vertical structure and interannual variability at each location on a stratified continental shelf, i.e. at least 48 current meter months at each measurement site. The required number of such sites in each 1° square would of course depend on the horizontal scales of variation. If these scales were determined by topography, then the number might vary from perhaps only one (per 1° square) on the central Grand Bank to several on parts of the topographically rugged Scotian and Labrador Shelves. Assuming then that, on average, four measurement sites were required in each 1° square to resolve

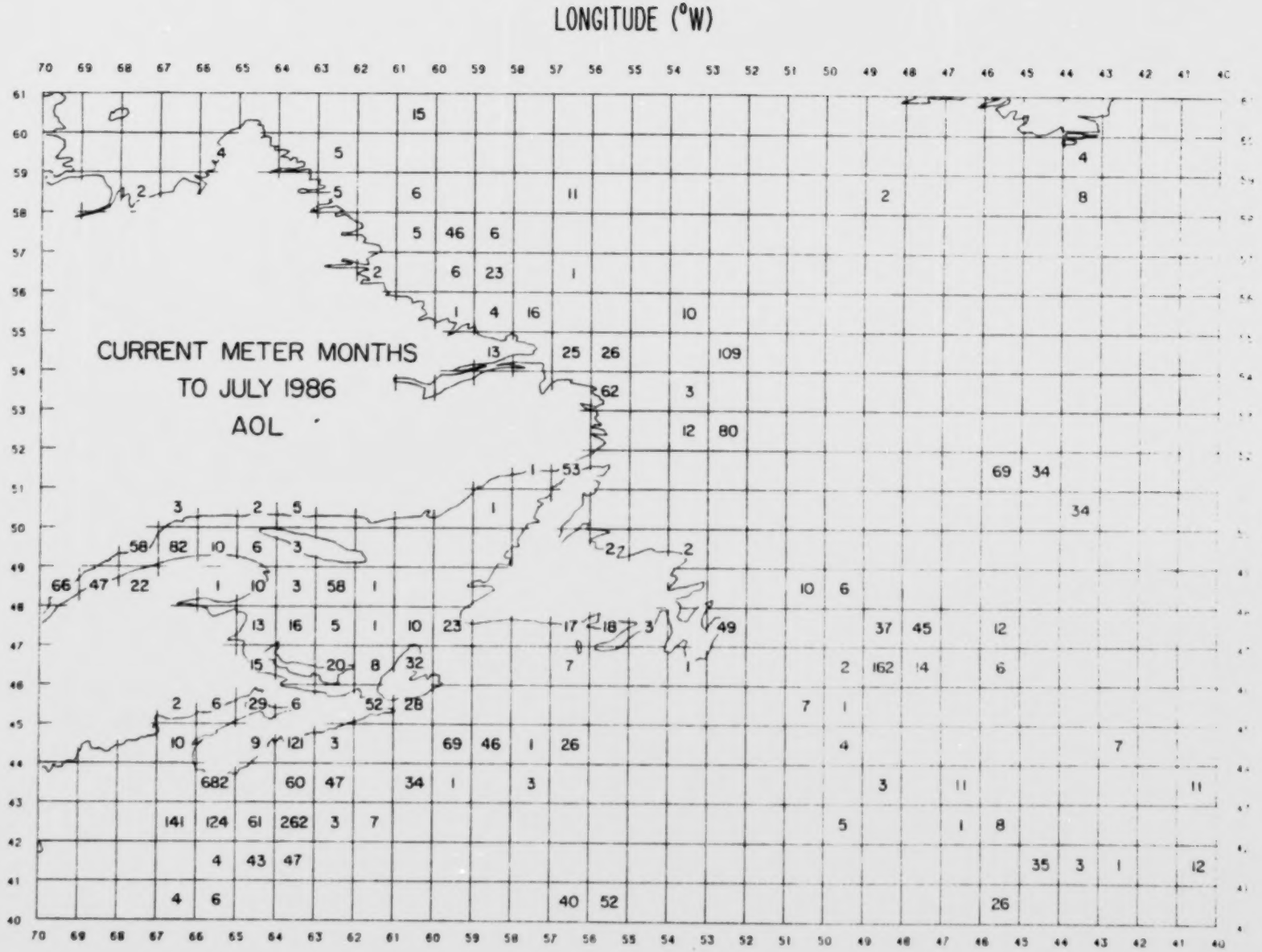


Fig. 2. Number of months of current meter data by 1° x 1° square, archived at AOL as of July 1986 (courtesy of D. Gregory, AOL).

the topographic scale variability referred to in Section 4.2.2, then approximately 30,000 current meter months of data would be required to obtain a first description of the seasonality of circulation with indications of vertical structure and interannual variability for the entire shelf region. In contrast, there are only about 3,300 current meter months of data for the same region in the AOL archive at present, 20% of which is in a single 1° square (Fig. 2). Furthermore, with approximately 100 current meters available in AOL, it is clear that meeting the stated requirements of the first category of fisheries questions alone would take several decades of concentrated effort.

It should be emphasized that two years of record may well be inadequate to resolve seasonal variability much less interannual variability, although it may be adequate to suggest that there is not a seasonal variation of significance to the fisheries question because of strong higher-frequency variability. Seasonal variability analyses have been reported for current measurements from at least three areas in the region of interest: for the outer Scotian Shelf (primarily Square 42-43°N, 63-64°W of Fig. 2 - Smith and Petrie 1982); for the Cape Sable area (primarily Squares 42-44°N, 65-66°W - Smith 1983); and for the southern flank of Georges Bank (not shown in Fig. 2 - Butman and Beardsley 1987). On the outer Scotian Shelf where the subtidal current fluctuations are primarily induced by wind events and deep-ocean eddies, Smith and Petrie (1982) found that the seasonal mean currents were generally smaller than the subtidal standard deviations, with only the cross-shelf component of near-surface current showing a consistent annual cycle in the 2 yr of record. For the Cape Sable area, Smith (1983) performed a least squares multiple regression analysis between the monthly mean currents and a mean annual cycle and its harmonics. In general, statistically significant means and annual cycles were found in the along-isobath (i.e. along the contour of constant depth) component of monthly mean current, suggesting that the available 22 mo of record was adequate for the determination of the seasonality of this current component. The means and seasonal variations, however, were not compared with any measure of the current variability at periods of less than a month associated with wind forcing and the tides, although such variability could affect the significance of the monthly mean currents to the fisheries questions. Using up to 4 yr of moored measurements at Station A on the southern flank of Georges Bank, Butman and Beardsley (1987) examined the seasonal variation of both the monthly mean currents and the standard deviations of the subtidal (i.e. tidal motions excluded) current variability about the monthly means. They found that the most significant means and seasonal cycles generally occurred in the along-isobath component of monthly mean flow, consistent with the well-known, seasonally varying, clockwise residual circulation around Georges Bank. The subtidal standard deviations, however, were generally of the same order of magnitude as the means and seasonal variations, leaving the fisheries significance of the latter unclear.

The conclusion is that, in general, the currently available quantity of current information for the Atlantic Canadian shelf is grossly inadequate for providing the seasonal description of circulation required by the first category of fisheries questions. There was, however, some discussion by the Working Group that the stated fisheries requirement for circulation information is excessive and unrealistic, particularly considering the

resources available for physical oceanographic measurement programs. Furthermore, statistical criteria have not been specified for evaluating the relative significance to the fisheries problems of the seasonal mean and long-term residual currents versus the strong higher-frequency current fluctuations present in most locations. In light of the lack of adequate current information and the need for further consideration of the fisheries requirement, the approach in Section 4.2 will be to provide a brief summary of the geographic distribution of available current measurements which appear to contain relevant information on seasonality. The adequacy of these measurements to meet the fisheries requirement in a rigorous statistical sense, however, will not be addressed.

4.1.3. Quantity of Available Data - Subsurface Temperature and Salinity

Figures 3 to 10 summarize by season and 1° x 1° square the number of temperature and salinity stations available from the Marine Environmental Data Service (MEDS) archive up to July 1986 (courtesy of J. Gagnon, MEDS). The number of temperature stations is taken as the sum of the number of stations (or casts) in the Nansen bottle, bathythermograph, conductivity-temperature-depth (CTD), and Integrated Global Ocean Services System (IGOSS) temperature data bases. The number of salinity stations is taken as the sum of the number of stations in the Nansen bottle, CTD, and IGOSS salinity data bases only.

The number of stations required to resolve the seasonal variation in the distributions of temperature and salinity will also depend on such a priori unknown factors as the horizontal scales of variation and the relative magnitudes of the interannual, seasonal, and high-frequency variability. As a rough yardstick for use in the present discussions, it is probable that each 1° x 1° square would have to be divided into at least four subareas on average and that at least ten stations per subarea per month would be required in order to obtain a first indication of the seasonal and spatial variability. This would mean that at least 120 stations would be required in each 1° x 1° square for each season, assuming the stations to be uniformly distributed in space and time. Of course, in many areas much denser coverage would be required for a rigorous statistical examination of spatial and temporal variability; moreover, in many cases the available data summarized in Figures 3 to 10 may not be adequately distributed in space (e.g. on the topographic scale) and time (e.g. across years).

Figures 3 to 6 suggest that there may be adequate data for a preliminary description of the seasonal distribution of temperature in most shelf areas. The most notable exception is the Labrador Shelf in winter and spring when a seasonal ice cover prevents extensive sampling. Other areas which do not appear to have an adequate data base for the required description of temperature variability are the northeastern Newfoundland Shelf in all seasons, the Grand Banks in fall and winter, the Gulf of St. Lawrence in winter, and the northeast Gulf of St. Lawrence in spring.

Comparison of Figures 7 to 10 with Figures 3 to 6 indicates that the quantity of available salinity data is generally less than one-half of the quantity of available temperature data. In winter (Fig. 7), the salinity

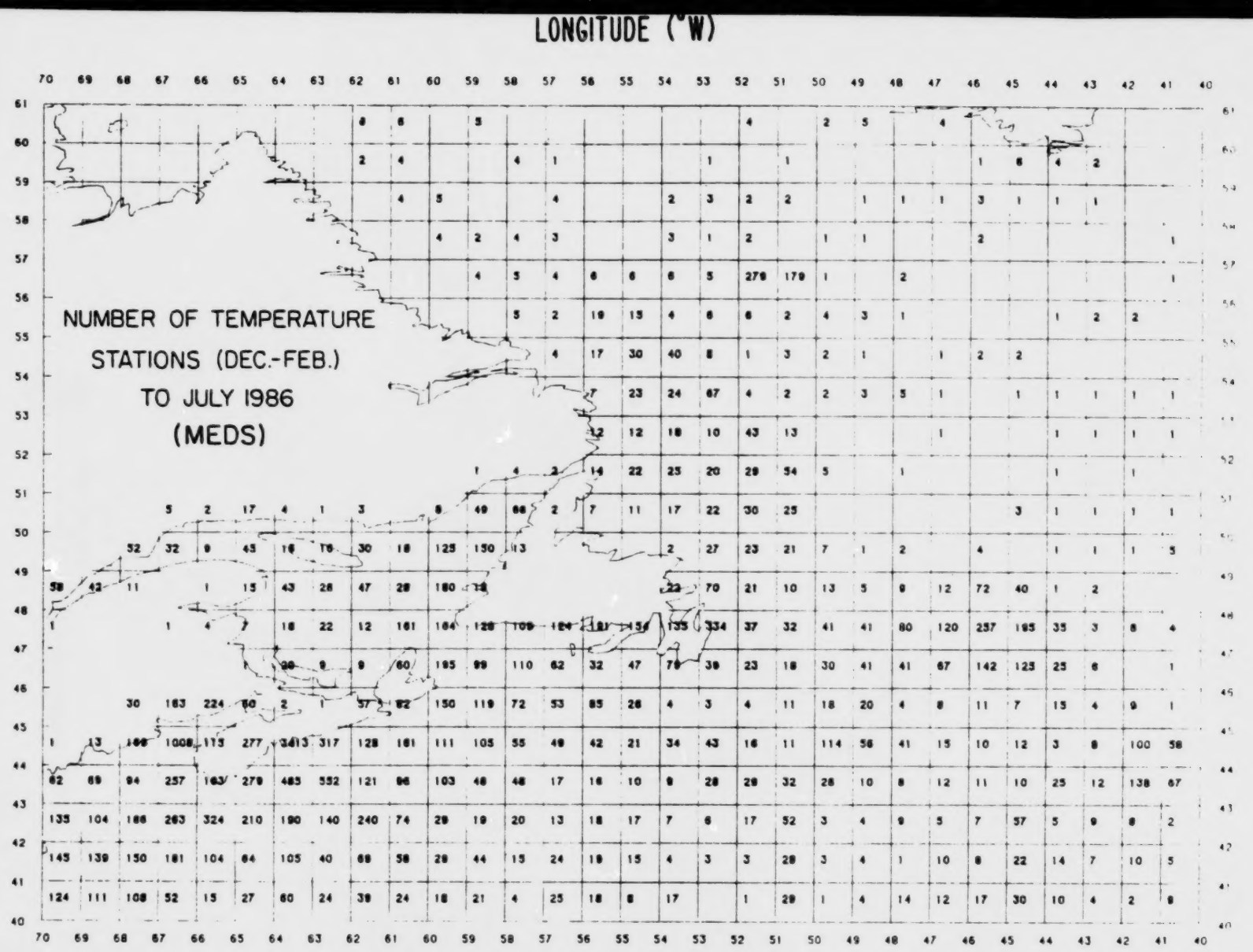


Fig. 3. Number of temperature stations by 1° x 1° square, in the MEDS archive (as of July 1986), for December to February (courtesy of J. Gagnon, MEDS).

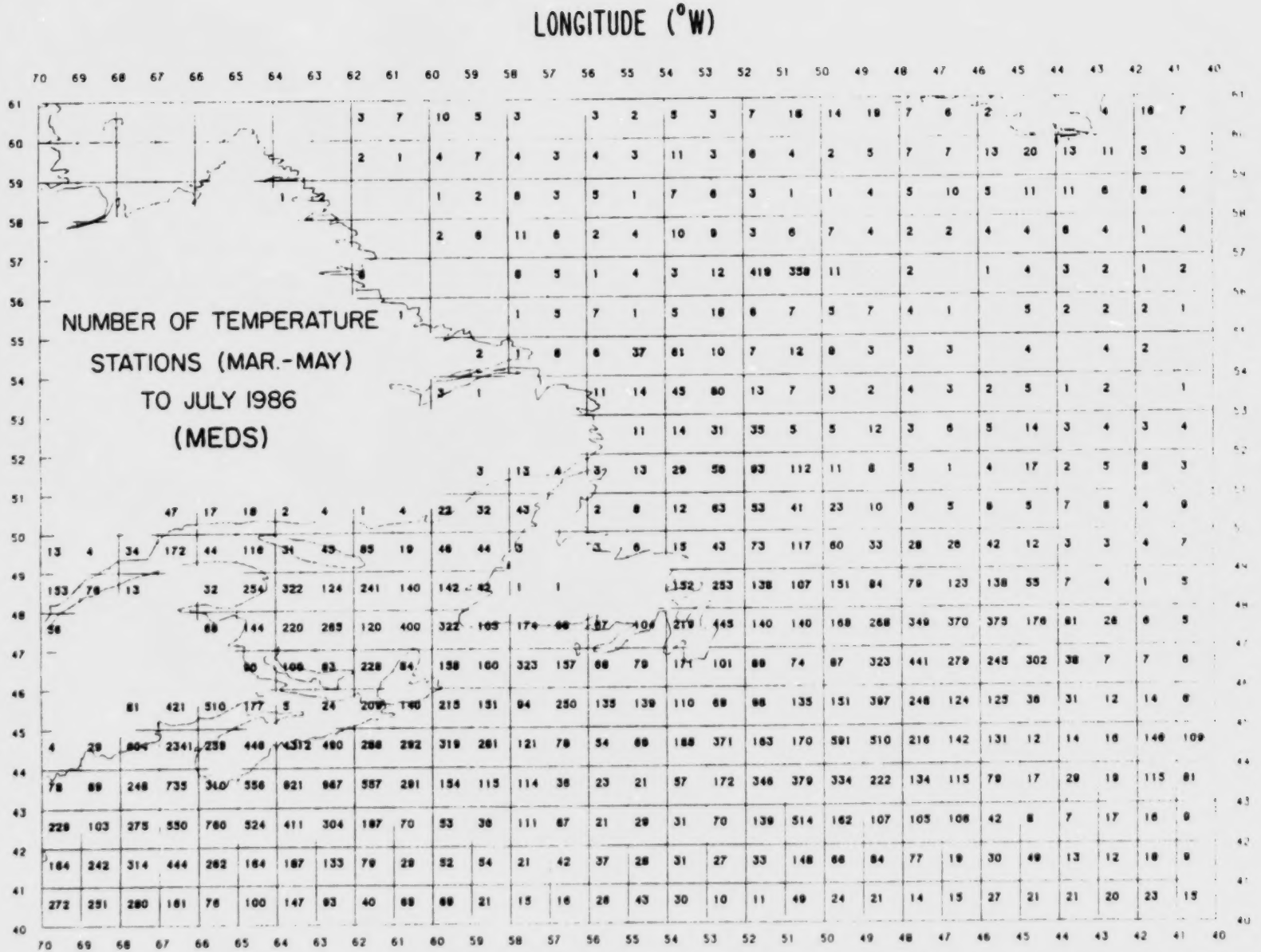


Fig. 4. Number of temperature stations by 1° x 1° square, in the MEDS archive (as of July 1986), for March to May (courtesy of J. Gagnon, MEDS).

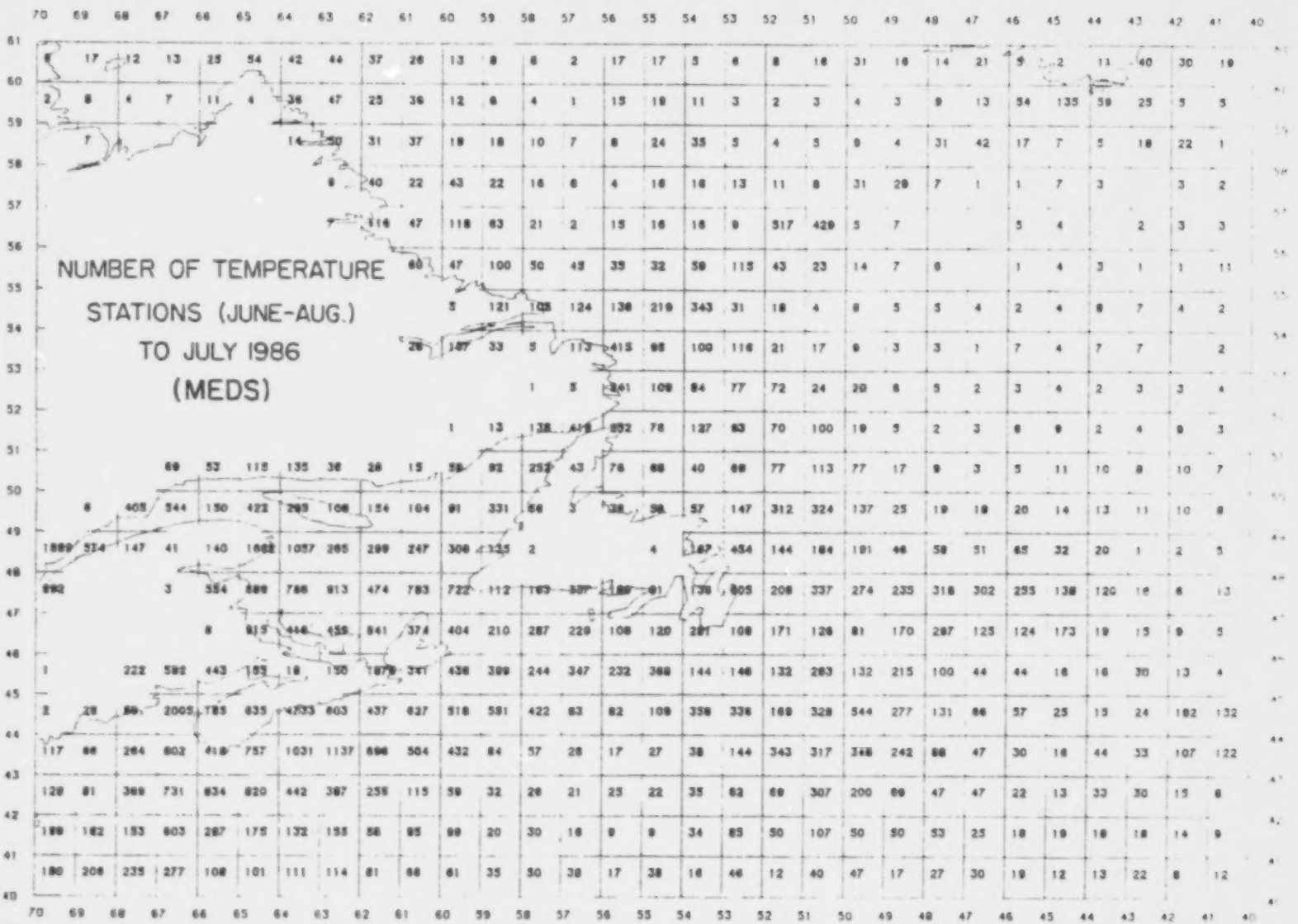


Fig. 5. Number of temperature stations by 1° x 1° square, in the MEDS archive (as of July 1986), for June to August (courtesy of J. Gagnon, MEDS).

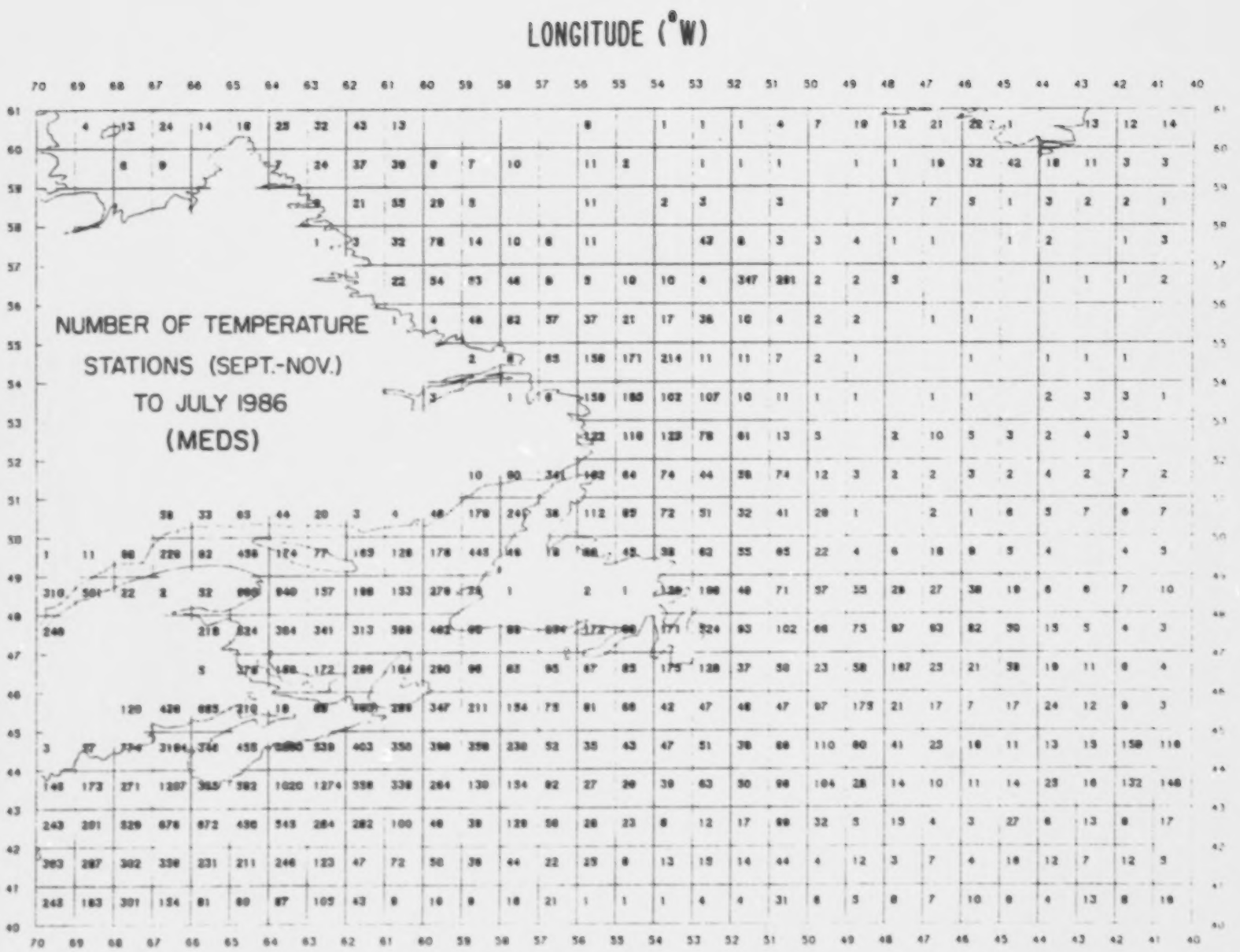


Fig. 6. Number of temperature stations by 1° x 1° square, in the MEDS archive (as of July 1986), for September to November (courtesy of J. Gagnon, MEDS).

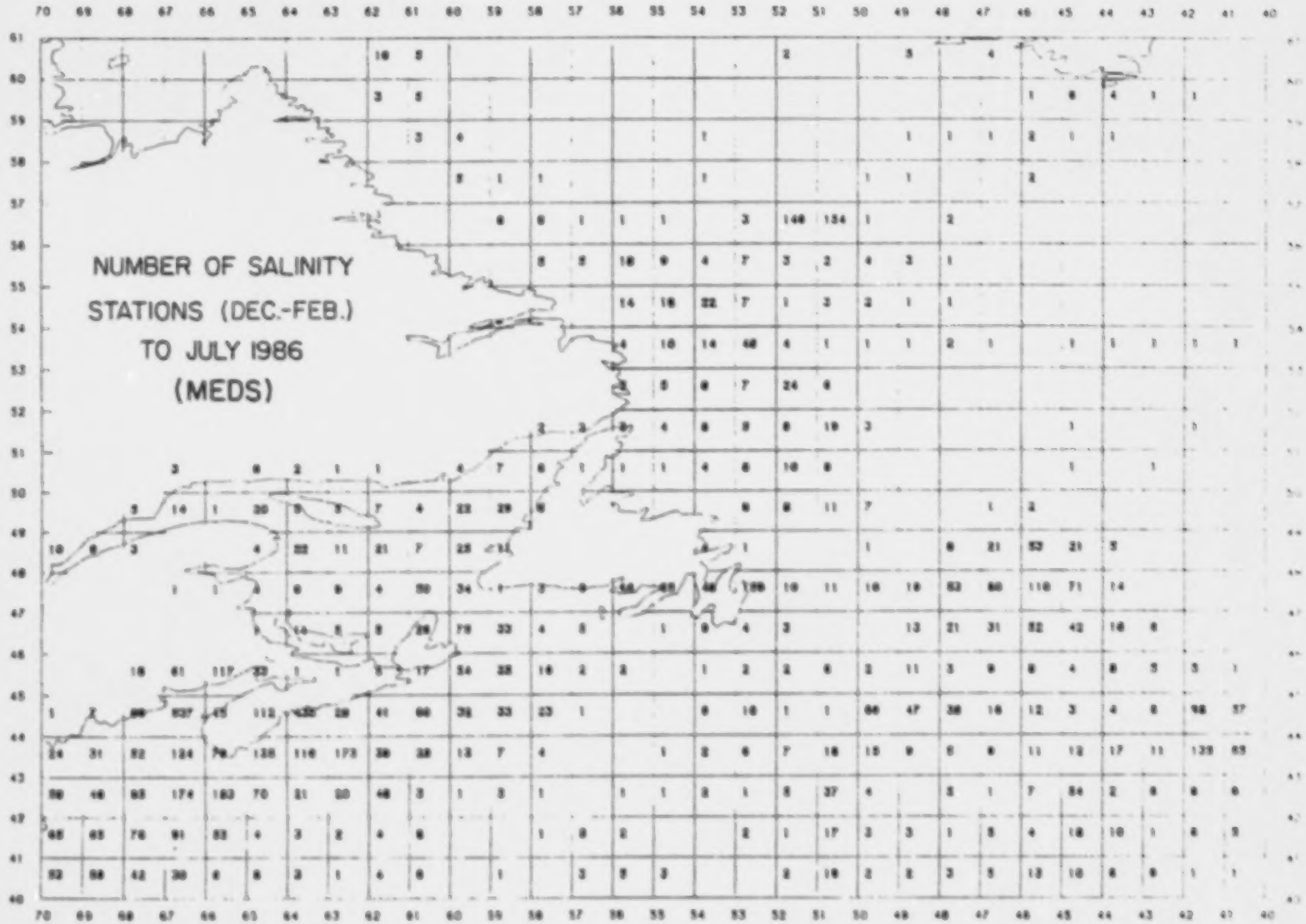


Fig. 7. Number of salinity stations by 1° x 1° square, in the MEDS archive (as of July 1986), for December to February (courtesy of J. Gagnon, MEDS).

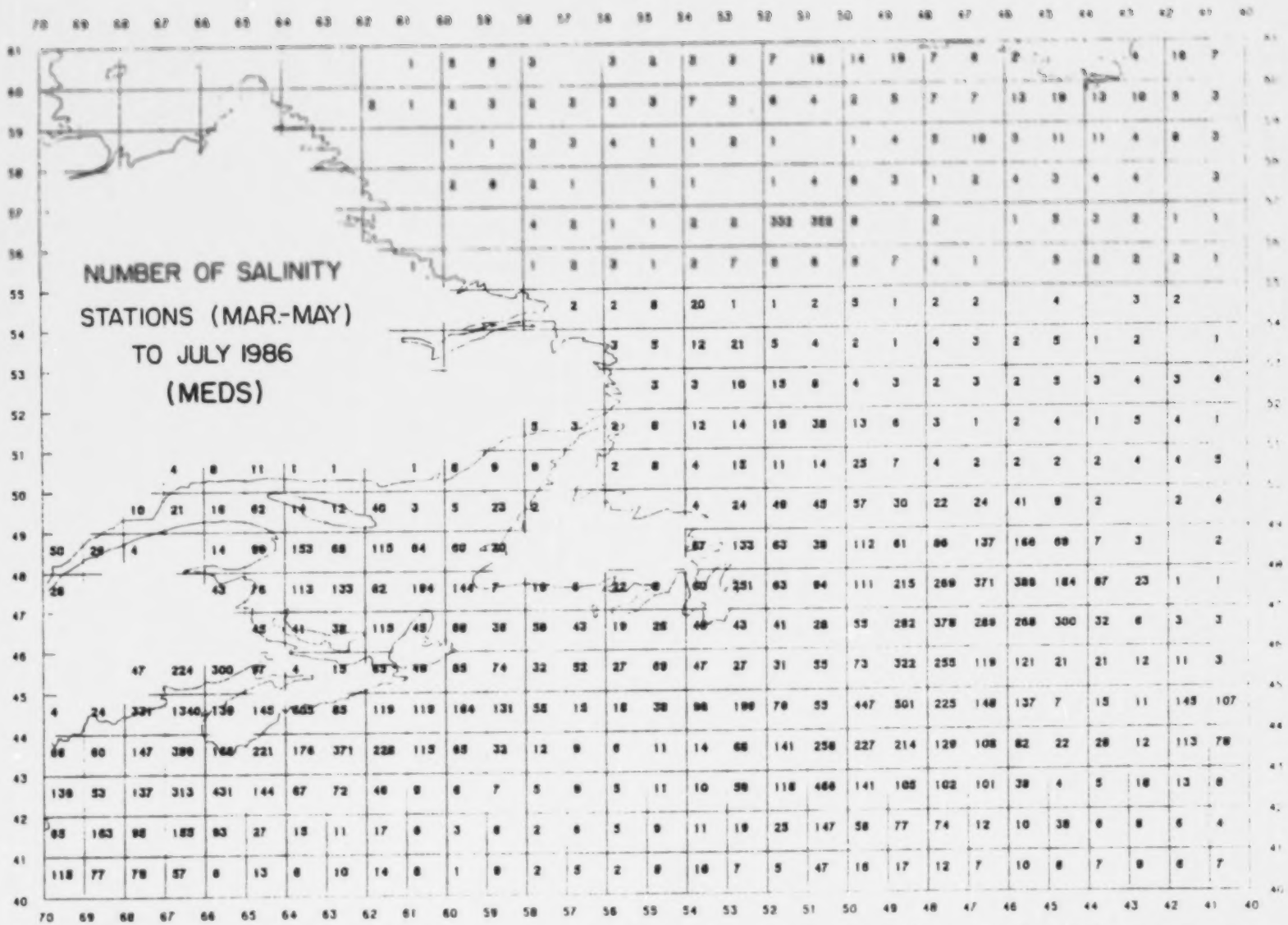


Fig. 8. Number of salinity stations by 1° x 1° sauare, in the MEDS archive (as of July 1986), for March to May (courtesy of J. Gagnon, MEDS).

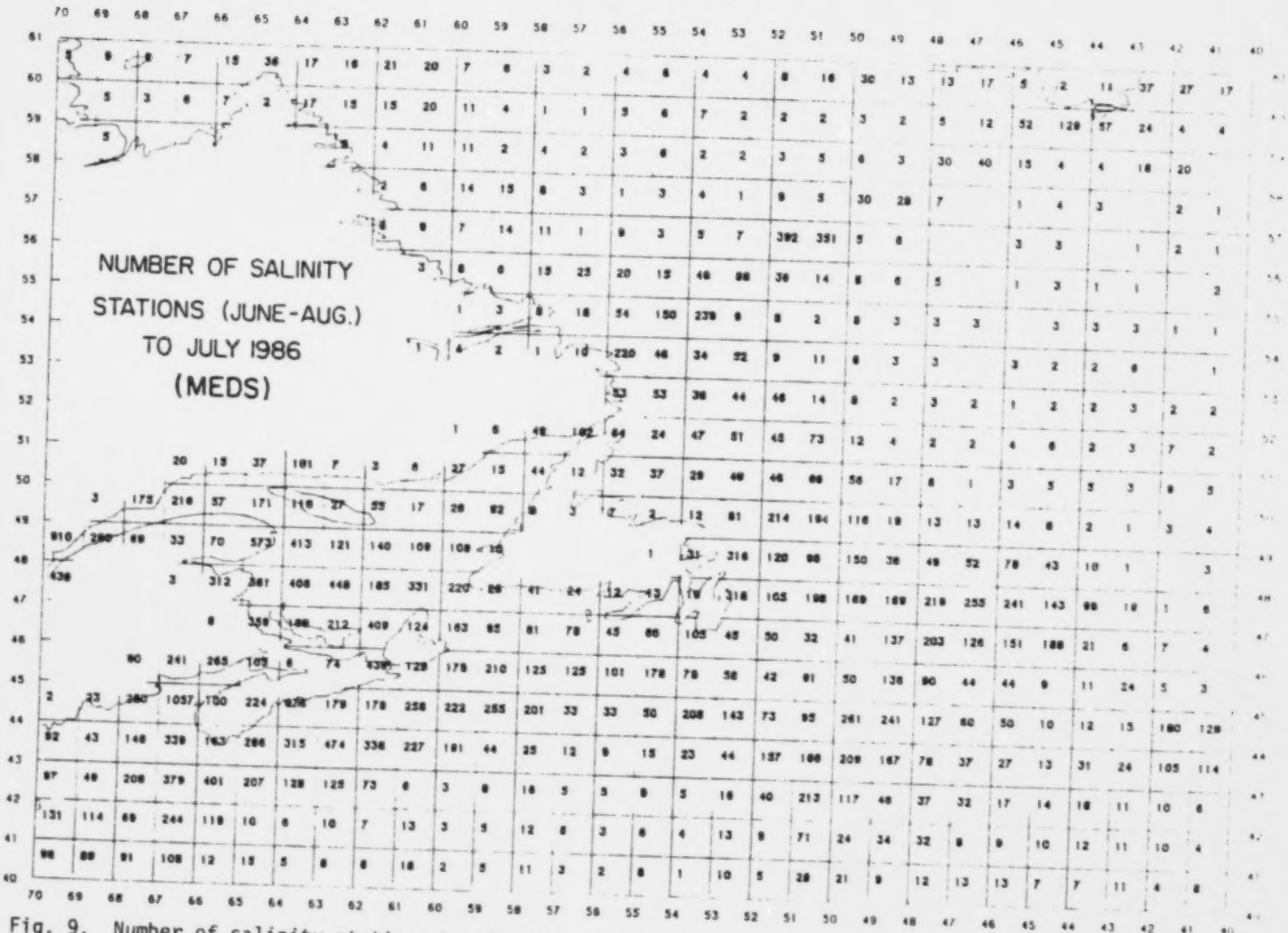


Fig. 9. Number of salinity stations by 1° x 1° square, in the MEDS archive (as of July 1986), for June to August (courtesy of J. Gagnon, MEDS).

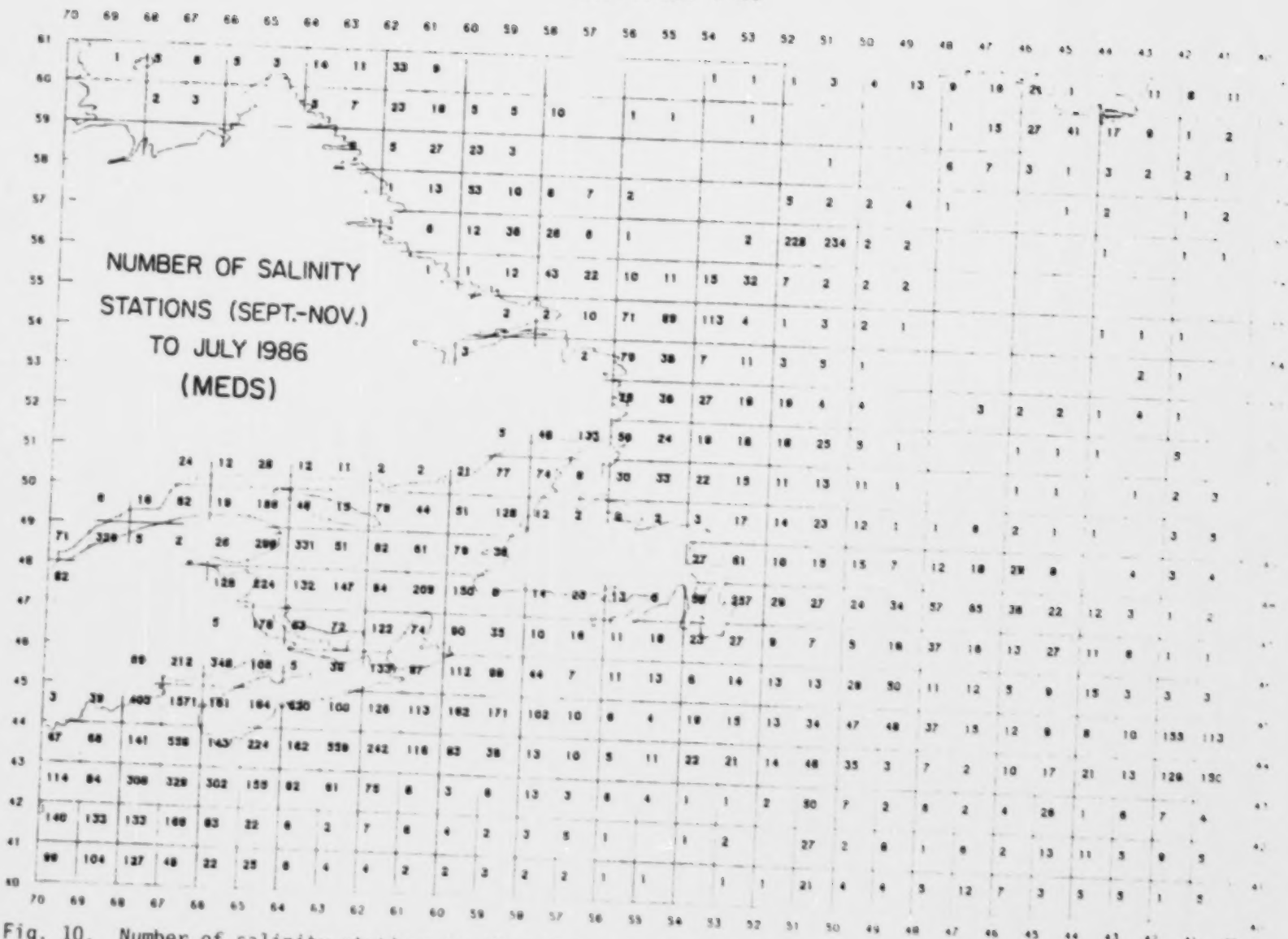


Fig. 10. Number of salinity stations by 1° x 1° square, in the MEDS archive (as of July 1986), for September to November (courtesy of J. Gagnon, MEDS).

data base appears to be inadequate to meet the fisheries requirement with the exception of a few areas: Flemish Cap, Avalon Channnel (Station 27), and parts of the Scotian Shelf and Gulf of Maine. In spring (Fig. 8) and fall (Fig. 10), the number of areas appearing to have adequate data is greater, including most of the Scotian Shelf and Gulf of Maine and parts of the Gulf of St. Lawrence. The data coverage is greatest in summer (Fig. 9), but there still appears to be an inadequate data base for much of the Labrador and Newfoundland Shelves and parts of the Gulf of St. Lawrence.

The determination of the adequacy of the available temperature and salinity data for providing the seasonal description appropriate to the first category of fisheries questions requires a rigorous statistical analysis of the spatial and seasonal variability in relation to temporal variability at other frequencies. This must be done on a region-by-region and season-by-season basis, and would require time and effort far beyond the capability of the present Working Group. The results of such an analysis could then be used in the context of sampling theory to examine the adequacy of the existing data and obtain firm estimates of the quantity of data required to meet the specified fisheries requirement. The approach in Section 4.3 will be to provide a brief summary of available data and existing studies and reports which are relevant to the seasonal description of temperature and salinity distributions, without addressing the adequacy of the data to meet the fisheries requirement in a rigorous statistical sense.

4.1.4. Comments and Recommendations

1. The specified fisheries requirement for seasonal descriptions of circulation and temperature and salinity distributions should be modified to include appropriate measures of the variability about the means and seasonal cycles, in order to assess the significance of the means and seasonal cycles to the fisheries questions. This will require specification, by the fisheries scientists, of the frequency range in which variability may be significant to the fisheries questions. As examples, the suitability of a particular bank as a spawning site may depend on the variability of temperature on time scales comparable to and longer than the larval emergence and maturation times (as well as on the seasonal mean temperature over the bank), or on current fluctuations that are energetic enough and at sufficiently low frequencies to result in larval displacements to less-favourable environments (as well as on the seasonal mean circulation). The appropriate frequency range may thus depend on the frequency spectrum of current variability and the relation of the horizontal excursions associated with the current variability to the topographic and other space scales, as well as on the time scales of the biological processes inherent in the fisheries question. Thus, this need for further specification of the fisheries requirement should be addressed through the interaction of fisheries scientists and physical oceanographers. It is recommended that, as an exploratory case, the appropriate criteria for the determination of the significance of the means and seasonal cycles of currents, temperature, and salinity required by the first category of fisheries questions be addressed for the species studied in the Fisheries Ecology Program in the Browns Bank area.

2. The discussion in this Section assumes that the topographic scale is a dominant space scale of the current, temperature, and salinity distributions on the Atlantic Canadian shelf. It is recommended that this assumption should be examined quantitatively for some representative regions, using objective analysis techniques along the lines of those proposed by P.C. Smith (unpubl. MS, 1985) for determining the space and time scales of temperature anomalies relative to the means and seasonal cycles.

3. Assuming that the first category of fisheries questions requires a seasonal description of circulation on the topographic space scale (also see discussion of topographic scale in Section 4.2), the available circulation information is grossly inadequate for the region as a whole, with adequate information appearing to be available for only a few areas (mostly notably, Georges Bank and the Cape Sable area including Browns Bank). Furthermore, it would be neither possible nor reasonable to attempt such a description (for the entire region) given the currently available physical oceanographic resources. It is recommended that fisheries scientists priorize, on an area-by-area basis, their requirement for descriptions of the seasonality of circulation patterns.

4. It is recommended that, pending the determination of the significance criteria discussed in Recommendation 1 above, the long-term means and seasonal cycles of the local along-isobath and cross-isobath components of the monthly mean current be determined for existing records extending over one year or more, following the procedure of Smith (1983). It is further recommended that the means and seasonal cycles of the standard deviations about the monthly means be determined for the along-shelf and cross-shelf components of subtidal current for these records, following Butman and Beardsley (1987). The results of these analyses should be examined for spatial patterns (e.g. cross-shelf variability) in the ratios of the mean current and the seasonal cycle's amplitude to appropriate measures of the higher-frequency variabiltiy.

5. It is recommended that, as a first step toward providing the required seasonal description of the temperature and salinity distributions on the Atlantic Canadian shelf, the monthly means (averaged over all years), standard deviations, and numbers of observations for standard depths and subareas corresponding to topographic features be calculated using the merged MEDS data base. This computation should be carefully assessed by objective analysis for the errors involved. The means and seasonal cycles of both the monthly means and their standard deviations should then be determined following Smith (1983) and Butman and Beardsley (1987), and used to assess the significance (on purely statistical grounds at this point) of any seasonal cycles and to identify areas where additional observations are needed. For regions where adequate data presently exist, atlases of the seasonal distributions of temperature and salinity could be considered.

6. As most of the important continental shelf fisheries are associated with bottom or near-bottom-dwelling fish or invertebrates, greater emphasis should be placed on the examination of variability in oceanographic

properties of bottom water. For fish which have preferences for temperature, current condition, etc., it is the variability of these factors where and near where they live that is important. Thus, in consideration of groundfish research questions in particular (except that of recruitment) it is perhaps more useful to consider the variability of temperature, for instance in terms of horizontal variability in space of given isotherms on the bottom rather than the customary examination of temperature variability on given locations in space. In this respect it is recommended that the merged MEDS data base be used to develop monthly maps of the bottom temperature and its variability averaged over all years for the entire Atlantic Canadian shelf.

7. As a comprehensive description of seasonal variability in circulation, temperature, and salinity would require massive effort and resources and may not elucidate the physical processes occurring on the Atlantic Canadian shelf, the appropriate strategy may be to attempt to obtain this description in high-priority areas only. It is recommended that fisheries scientists priorize the areas and seasons for which seasonal descriptions of temperature and salinity distributions are required, and where possible state the minimum seasonal and spatial variations in the required parameters that would be significant to the fisheries questions.

4.2. CIRCULATION

4.2.1. Broad Scale

The description of circulation on the Atlantic Canadian shelf is facilitated by the presence of a general southward and southwestward drift in the region, associated primarily with the Labrador Current on the Labrador and northeastern Newfoundland Shelves and the Grand Banks of Newfoundland, and primarily with the coastal discharge of freshwater (particularly from the St. Lawrence River) in the Gulfs of St. Lawrence and Maine and on the Scotian Shelf. Although this drift is disrupted in some areas, particularly those with variable bottom topography, the observation that the mean current is generally along-shelf (with the coast to the right) and the physical constraints of continuity of flow and potential vorticity conservation combine to provide the possibility that representative descriptions of the cross-shelf structure and seasonal variability in the broad-scale, along-shelf flow can be obtained from a limited number of along-shelf positions.

Our present understanding of the cross-shelf structure and seasonal variability of the broad-scale, along-shelf flow is based primarily on the following:

1. Moored current measurements, hydrographic sections, and coastal sea level observations across Hamilton Bank on the southern Labrador Shelf, taken partly in a program currently underway in AOL

2. Hydrographic sections taken over many years and a limited number of moored current measurements across the northern Grand Bank, the northeastern Newfoundland Shelf, and Flemish Cap (roughly along 47°N)

3. Moored current measurements and coastal sea level observations in the Strait of Belle Isle

4. Hydrographic sections distributed across the Gulf of St. Lawrence and moored current measurements in the St. Lawrence Estuary

5. Hydrographic sections and moored current measurements across the Cabot Strait

6. Hydrographic data on the so-called Halifax Section across the Scotian Shelf

7. Moored current measurements on the outer Scotian Shelf taken as part of AOL's Shelf-Break Experiment

8. Moored current measurements off southwest Nova Scotia, taken as part of AOL's Cape Sable Experiment

9. Moored current measurements on Georges Bank, taken as part of the (USA) New England Outer Continental Shelf Physical Oceanography Program

10. Moored current and bottom pressure measurements, and hydrographic sections across the New England Shelf south of Cape Cod, taken as part of the (USA) Nantucket Shoals Flux Experiment

These observational programs have been complemented by less-extensive mooring programs at other sites, satellite-tracked drifter tracks, other surface- and bottom-drifter studies, inferences from water-mass property distributions (e.g. temperature, salinity, O^{18}/O^{16} and ice distributions), and numerical model predictions.

4.2.1.1. Comments and Recommendations:

1. Some information on the cross-shelf structure and seasonality of the broad-scale component of circulation (i.e. the along-shelf flow) is available or being collected from all the major shelf regions (Labrador Shelf, Newfoundland Shelf, Gulf of St. Lawrence, Scotian Shelf, Gulf of Maine). Nevertheless, the cross-shelf structure and seasonal variability in these areas cannot be considered as well described, with the possible exception of the Cape Sable region off southwestern Nova Scotia. Furthermore, much of the available information is derived from hydrographic sections, from which only the baroclinic component of flow can be inferred in general.

2. The existing information on cross-shelf structure and seasonality of the along-shelf flow is particularly lacking in moored current measurements on the entire Newfoundland Shelf.

3. The geographic areas to which the existing information on the broad-scale circulation may be extrapolated the least (due primarily to topographic effects) appear to be:

   - the northern Labrador Shelf
   - the northeastern Newfoundland Shelf
   - the southern Grand Bank
   - the Newfoundland Shelf south of Newfoundland
   - the central Gulf of St. Lawrence
   - the eastern Scotian Shelf
   - the northern Gulf of Maine

4. It is recommended that, as an extension of the analysis outlined in Recommendation 4 of Section 4.1, the seasonal variation of the integrated (across the shelf) along-shelf transport be examined for locations from which adequate moored measurements are available. It is further recommended that the results of this analysis be used in a review paper summarizing the evidence for continuity of the broad-scale flow throughout the region and the consistency of the seasonality observed on the various cross-shelf sections.

5. The Cape Sable Experiment is a model example of the type of observational program required to address the questions of cross-shelf structure and seasonality of the broad-scale circulation: a detailed cross-shelf array for two or more years, allowing determination of the cross-shelf scales of the flow and leading to the identification of a reduced scale program for monitoring seasonality in flow in later years (if required).

4.2.2. Topographic Scale

The existing moored current measurements and drifter tracks from areas of along-shelf variability in bottom topography and coastline indicate that the broad-scale drift described above is dominated in some areas by circulation features related to the topography and coastline. The best-documented examples of circulation features on this space scale are the observations of a component of flow in a clockwise direction around a number of the offshore banks in the region (Belle Isle Bank, Browns Bank, Flemish Cap, Georges Bank), of weak mean flows on the crest of some offshore banks (Hamilton Bank, Grand Bank, Georges Bank), of enhanced cross-shelf mean flow in some saddles (e.g. Cartwright Saddle) and channels (e.g. Northeast Channel), and of localized gyres in some bays (e.g. St. Georges Bay, N.S.). In the present context, these circulation features are of interest on two counts. First, they may be directly relevant to the fisheries questions of definition of populations and stocks and recruitment success. Secondly, they are disruptions to the broad-scale flow discussed above, and hence their structure is relevant to the continuity of this flow and the representativeness of the existing information on cross-shelf structure and seasonality.

Several dozen of these topographic features with the space scale of interest here (10^2 km) can be identified readily: six offshore banks on

the Labrador Shelf, as well as the intervening saddles and the marginal trough; eight major bays on the east and south coasts of Newfoundland; Flemish Cap and four banks on the Grand Banks of Newfoundland, as well as the intervening and inshore channels; four straits, a major channel and estuary, and several bays adjoining and lying in the Gulf of St. Lawrence; approximately nine banks and intervening basins and channels on the Scotian Shelf; and two major banks, a major bay, and several basins and channels adjoining or lying within the Gulf of Maine. As the mean circulation pattern has been determined for only a small fraction of these features, and the seasonality determined for only a few of them, this information will be summarized; and the gaps in understanding will not be identified explicitly.

On the Labrador Shelf the "topographic-scale" circulation pattern is best described in the Hamilton Bank area where some information on seasonality is available. There are also moored measurements of the summertime circulation pattern over and around Belle Isle and Makkovik Banks, and in Cartwright Saddle, and of the local currents in some seasons at several other sites.

On the Newfoundland Shelf, there are moored measurements which provide information on the seasonal variation in circulation in the Avalon Channel, in the Hibernia region, in the approaches to Fortune Bay, and in Flemish Pass. There are also geostrophic calculations of the seasonal variation in flow through Flemish Pass and information on the summertime circulation off Fogo Island, in Trinity and Conception Bays, and in the vicinity of canyons on the eastern side of the Grand Bank.

For the Gulf of St. Lawrence, there is information on the seasonal variation of current in Cabot Strait based on moored measurements and geostrophic calculations, and in the Strait of Belle Isle based on moored measurements and coastal sea level observations. There are also extensive moored measurements which provide information on the summertime circulation in the St. Lawrence Estuary, in the northwestern Gulf in the vicinity of the Gaspé Current, and in St. Georges Bay.

On the Scotian Shelf the mean circulation and its seasonality based on moored measurements have been described for the shelf-break region in the vicinity of the Scotian Gulf, for Browns Bank, and for the near-shore region off Shelburne. There have also been extensive moored measurements made on the inner Scotian Shelf off Halifax in winter and less-extensive moored measurements made at a number of other sites.

In addition to the seasonal description of the Browns Bank circulation, there have been extensive observations of the seasonality of flow through Northeast (at depth) and Great South Channels, and of the circulation on and around Georges Bank. Moored measurements exist also for the summertime currents in Minas Basin and Chignecto Bay, of the wintertime currents in the western Gulf of Maine, and of the year-round currents at one site in the interior Gulf. A moored observational study of interbasin circulation in the interior Gulf over 1 yr is currently being carried out by American scientists.

4.2.2.1. Comments:

1. The seasonality of the topographic-scale circulation has been described for only a small fraction of the Atlantic Canadian shelf.

2. The topographic-scale circulation features with the most detailed descriptions at present appear to be the clockwise circulations around Browns and Georges Banks.

3. There is very little information on the seasonality of the circulation patterns over the offshore banks in the northern Labrador Shelf, on the Newfoundland Shelf south of Newfoundland, and on most of the Scotian Shelf.

4. There is also very little information on the circulation patterns and their seasonaltiy in the bays on the eastern and southern coasts of Newfoundland.

4.3. TEMPERATURE AND SALINITY DISTRIBUTIONS

The available temperature and salinity data for the Atlantic Canadian shelf also show variability on the broad and topographic space scales discussed above. As several studies of temperature and salinity variability on other space scales are available or underway, the present discussion will focus on these studies and comment on their implications for the availability of broad- and topographic-scale descriptions. The discussion is organized on the basis of sea-surface temperature observations and subsurface temperature and salinity observations.

4.3.1. Sea-Surface Temperature

The largest set of water mass property observations from the region is the set of sea-surface temperature observations reported by merchant ships. The spatial, seasonal, and interannual variability in these observations has been analyzed in several recent studies.

Trites et al. (1985) grouped the observations received via the (USA) Fleet Numerical Oceanography Centre (FNOC) for the region between Cape Hatteras and Hamilton Bank by month, for the period 1971-83, into 19 areas of 1° latitude by 3 or 4° longitude. In addition to the pronounced seasonal cycle, they found a broad-scale variation of decreasing temperature with latitude and a large-scale interannual variation with opposite phases north and south of the Gulf of Maine.

Loucks and Trites (1985) grouped the "Marine Deck" observations (achieved at the [USA] National Climatic Center [NCC]) for the region between Cape Hatteras and Cape Farewell for 1940-80, by month into 24 areas selected to correspond to fishing banks and oceanographic features. Their examination of the monthly and seasonal anomalies using correlation and empirical orthogonal function analyses showed that there is interannual variability in all seasons on both the broad scale (over the entire region) and the large scale as found by Trites et al. (1985).

Loucks et al. (1986) carried out further empirical orthogonal function and cross-spectral analyses on the Marine Deck observations for the period 1946-80, grouped by the same areas as Loucks and Trites (1985). In addition to their results pertaining to anomalies (interannual variability) and their relation to atmospheric variables, they showed the average distributions of sea-surface temperature by month for the entire region. These maps confirm the existence of a broad-scale pattern of decreasing temperature with latitude in all months.

Information on the seasonal variation of sea-surface temperature is also available from long observational records at particular coastal sites such as St. John's, Entry Island, Halifax, St. Andrew's, Boothbay Harbour, and Boston (see Chapter 7). Information on the spatial pattern of sea-surface temperature observations also exists for most of the oceanographic bottle, bathythermograph, and CTD stations discussed in the next section, and is becoming increasingly available for all regions through satellite infrared imagery. For a discussion of the spatial and temporal variability of sea-surface temperature in the Scotian Shelf and Gulf of Maine regions, see Akenhead et al. (1981, Section 3.5).

4.3.1.1. Comments and Recommendations

1. The Loucks et al. (1986) monthly maps can be considered a broad-scale description of the seasonal variation in sea-surface temperature on the Atlantic Canadian shelf, although the analysis did not include observations from all areas.

2. It is recommended that there be an intercomparison and assessment of the FNOC, NCC, and MEDS data bases of sea-surface temperature for the Atlantic Canadian shelf.

3. It is recommended that those data bases that are judged reliable be combined and used in an objective analysis of the spatial distribution of sea-surface temperature on the Atlantic Canadian shelf by month (average over all years). The results of this analysis could be presented in an atlas, showing the monthly mean temperature distribution, as well as the spatial distribution of variability about the monthly mean patterns.

4. It is recommended that there be a study to determine the fraction of the water column for which sea-surface temperatures and their anomalies are representative. This study could include a correlation analysis of the above-surface data with the subsurface data described in the next section.

4.3.2. Subsurface Temperature and Salinity

Partial descriptions of the seasonal variation in the subsurface temperature and salinity distributions are available or becoming available for most of the Atlantic Canadian shelf, although in many cases it is not clear that the data base used is adequate to provide a statistically reliable description.

Lazier (1982) has described the seasonal variability in temperature and salinity on the Labrador Shelf on the basis of 3,244 oceanographic bottle stations obtained between 1928 and 1979. These stations, obtained from the MEDS archive, were sorted by month or season and by area on a cross-shelf grid consisting of 17 strips lying in the along-shelf direction. The analysis showed that the dominant feature of the temperature and salinity patterns is an abrupt change over the shelf break and that there is a seasonal cycle in temperature and salinity at all depths on the shelf. The analysis also showed a weak along-shelf temperature gradient in fall, while more recent hydrographic surveys indicate some spatial structure on the topographic scale. The seasonal variability of the temperature and salinity distributions on this scale, however, has not been described.

Drinkwater and Trites (1986; 1987) have sorted the oceanographic bottle data archived by MEDS for the Newfoundland and Scotian Shelves up to 1982, by month over all years and into areas corresponding to topographic and oceanographic features. For the Newfoundland Shelf, 17,688 stations were sorted by month into 44 areas; and for the Scotian Shelf, 6,205 stations were sorted into 35 areas. These reports provide seasonal descriptions of the temperature and salinity patterns on the space scale of interest to fisheries scientists, although the number of observations in some areas may be inadequate to provide a reliable seasonal description.

As part of a heat and salt budget study of the Gulf of St. Lawrence, Bugden (1981) has sorted the oceanographic bottle and bathythermograph data for the period from 1947 to 1974 into four regions by month. Approximately 13,600 temperature soundings and 3,600 salinity soundings were included. This study provides a seasonal description of the large-scale temperature and salinity patterns in the Gulf but does not have the resolution required to resolve any topographic scale patterns.

Godshall et al. (1980) have summarized the oceanographic bottle and CTD data by month and $0.5^{\circ} \times 0.5^{\circ}$ squares for the shelf area between the Strait of Canso and Long Island, excluding the Bay of Fundy. They show the monthly averaged distributions of temperature and salinity at the surface and 125 m levels for March, June, August, and November, indicating a dominant large-scale variation with some topographic-scale variability.

The temperature-salinity characteristics of the Gulf of Maine have been described by Hopkins and Garfield (1979) on the basis of the eight seasonal cruises by Colton, Marak, Nickerson, and Stoddard (1968) in 1964-66, while Hopkins and Garfield (1981) have described the seasonal variation of temperature and salinity over Georges Bank using the (USA) National Ocean Data Center database. The springtime distribution of water masses in the Gulf of Maine has recently been described by Brooks (1985) on the basis of surveys in 1982-84.

In addition to these region-wide descriptions of temperature and salinity distributions, information on the seasonal and spatial variability of subsurface temperature and salinity in particular areas exists as follows.

1. Moored temperature measurements have been made concurrently with many of the moored current measurements described in Section 4.2.

2. Moored conductivity measurements, used to derive salinity, are now being made concurrently with many moored current measurements.

3. Summertime cross-shelf hydrographic sections have been made in most years between 1951 and 1973 on six lines on the Labrador and Newfoundland Shelves: Seal Island-Hamilton Bank section, Cape Bonavista section, St. John's-Flemish Cap section, St. John's-Southeast Shoal section, Green Bank-southeastern Grand Bank section, and St. Pierre Bank-southwestern Grand Bank section. Since 1973 the latter two lines have been sampled only occasionally, though one attempt was made each year to occupy most of the four more northern lines.

4. Descriptions of the seasonal variation in the cross-shelf distribution of temperature and salinity are available for Cabot Strait, the Halifax line, the Cape Sable line, and the Nantucket Shoals Flux Experiment line.

5. Long records of monthly observations of temperature and salinity exist for a number of offshore lightships and monitoring sites: Station 27, Sambro Lightship (temperature only), Lurcher Lightship (temperature only), Prince 5, Portland Lightship, and Boston Lightship.

6. Moored bottom temperature measurements have been made at a large number of (mostly near shore) sites throughout the region in recent years using Ryan thermographs - at over 80 sites in the DFO Newfoundland Region, over 60 sites in the DFO Scotia-Fundy Region, and over 110 sites in the Gulf. Although year-round measurements have been made at some sites, most of the measurements are for the spring to fall period only.

7. An extensive bottom temperature and bathythermograph data base has been accumulated by the fisheries research fleet at each fishing station occupied during the diverse surveys.

The above discussion summarizes the availability of region-wide descriptions of temperature and salinity distributions and the existence of temperature and salinity data. It should be emphasized that only a fraction of the existing data is included in the available descriptions and that not all of the existing data is available through the MEDS archive.

4.3.2.1. Comments and Recommendations:

1. Some description of the seasonal variability in the distribution of subsurface temperature and salinity is available or becoming available for all regions of the Atlantic Canadian shelf. The available descriptions are generally based on only a fraction of the existing data base and generally only resolve the broad-scale and large-scale patterns.

2. There is a noticeable lack of interpretative descriptions of the water mass properties on the Newfoundland Shelf.

3. It is recommended that the present MEDS effort towards creating a merged data base of oceanographic bottle, bathythermograph, and CTD

observations be supported. Upon the availability of such a merged data base, the determination of means and seasonal cycles on the topographic scale (Recommendation A5) should proceed.

CHAPTER 5. THE ROLE OF PHYSICAL OCEANOGRAPHIC PROCESSES IN THE STUDY OF AVAILABILITY CHANGES IN FISHERIES

The second category of fisheries research questions involves temporal changes in availability of fisheries resources to either commercial fisheries resources or research surveys. Two examples are considered in some detail: northern cod availability to the inshore fishery of eastern Newfoundland and Labrador (Section 5.1), and silver hake migration onto the Scotian Shelf (Secton 5.2).

5.1. AVAILABILITY OF ATLANTIC COD TO THE INSHORE FISHERY OF EASTERN NEWFOUNDLAND AND LABRADOR

5.1.1. The Fisheries Problem

The Atlantic cod (Gadus morhua) of NAFO Divisions 2J, 3K, and 3L, commonly referred to as "northern cod," support commercially important inshore and offshore fisheries off eastern Newfoundland and Labrador. It has been long recognized (e.g. Templeman and Fleming 1956; Templeman 1966), and supported more recently by extensive tagging studies (e.g. Templeman 1979; Lear 1984), that the cod undergo an annual cycle of inshore-offshore migration. In March-June, the northern cod spawn on the outer slopes of the northeastern Newfoundland and Labrador Shelves, generally at depths in excess of 250 m and at bottom temperatures of about 3°C, and primarily between Harrison Bank and the northern Grand Bank (Lear and Green 1984). During this spawning period and the preceding winter while the cod are overwintering in the deep, relatively warm areas of the shelf and slope, there is a lucrative offshore fishery by otter trawls.

After spawning, beginning in April and reaching a peak in June, the spent adult cod migrate westward and southward toward the Newfoundland and Labrador coasts where they feed and are exploited by an inshore fishery using small vessels and a variety of gear. There is considerable interannual variability, however, in the apparent availability of northern cod to this fishery (e.g. Lear et al. 1986). It has been postulated (Templeman 1979) that the adults are homing to the general areas where they grew up as immature fish, and there have been suggestions (e.g. Akenhead et al. 1982) that the route and timing of the inshore migration may be related to the inshore spawning migration in May-June of capelin (Mallotus villosus), the cod's primary prey. There have also been suggestions (e.g. Templeman 1966; Lear and Green 1984) that variability in the cod's migration and location, and hence in their availability to the inshore fishery, is related to variability in the physical oceanographic environment, particularly to variability in water temperature.

5.1.2. Background Physical Oceanography

The primary physical oceanographic information from much of the area of interest, particularly from the northeastern Newfoundland Shelf, comes from hydrographic data; but an increasing quantity of moored observations from the southern Labrador Shelf and the northern Grand Bank region is becoming available, and numerical models for circulation and ice distribution are being developed.

The best available description of currents and hydrographic properties in the area remains that provided by Smith et al. (1937) based on geostrophic calculations and hydrographic surveys carried out in the summers of 1928, 1931, and 1933-35. Representative distributions of along-shelf current, temperature, and salinity are shown in Figures 11 and 12 for cross-shelf sections off Belle Isle, White Bay, and St. John's in July-August 1931. The residual circulation in the area is considered to be generally dominated by the southward-flowing Labrador Current (also see Petrie and Anderson 1983), with inshore and offshore branches apparent in 1931. There is also some suggestion of a cyclonic "eddy" on the inner shelf off White Bay in 1931, as evidenced by the northward current at mid-shelf, although the persistence of this feature and of the apparent positions of the Labrador Current's branches is not well known. The temperature sections show that the shelf is dominated by very cold water, apparently arising from advection from the north and wintertime convective cooling. This water forms a thick intermediate layer in summer, overlain by a shallow seasonal thermocline and overlying slightly warmer water apparently intruding onto the shelf from offshore. The intrusion of offshore slope water onto the shelf is also apparent in the salinity distribution, which closely resembles the classical picture for the eastern North American shelves to the south.

The structure and interannual variability of the cross-shelf temperature field, and of the cold intermediate layer in particular, are further illustrated in Figure 13 from Templeman (1975), which shows the average, lowest, highest, and 1972 and 1973 values of temperature on a cross-shelf section off Cape Bonavista occupied by the former St. John's Biological Station in July-August of 1951-65 and 1969-73. The extent and heat content of the layer varies from year to year, with the minimum temperature of less than -1°C and the maximum thickness generally occurring over the inner shelf, perhaps associated with the inshore branch of the Labrador Current (Fig. 11 and 12).

The seasonal variability of the temperature field is illustrated in Figures 14 and 15, which show the vertical distribution of the monthly mean temperatures calculated by Drinkwater and Trites (1986) for four subareas (Fig. 16) in the region, based on the MEDS archive of hydrographic bottle data. It can be seen that a thick layer of water with subzero temperature develops in winter and persists through the summer into fall. The overlying shallow thermocline, which develops in spring and persists into fall, is generally confined to the upper 40 m of the water column, and there is no clear suggestion of a seasonal variation in the temperature of the underlying, warmer water. Additional features of the temperature field that are apparent in these summary figures include:

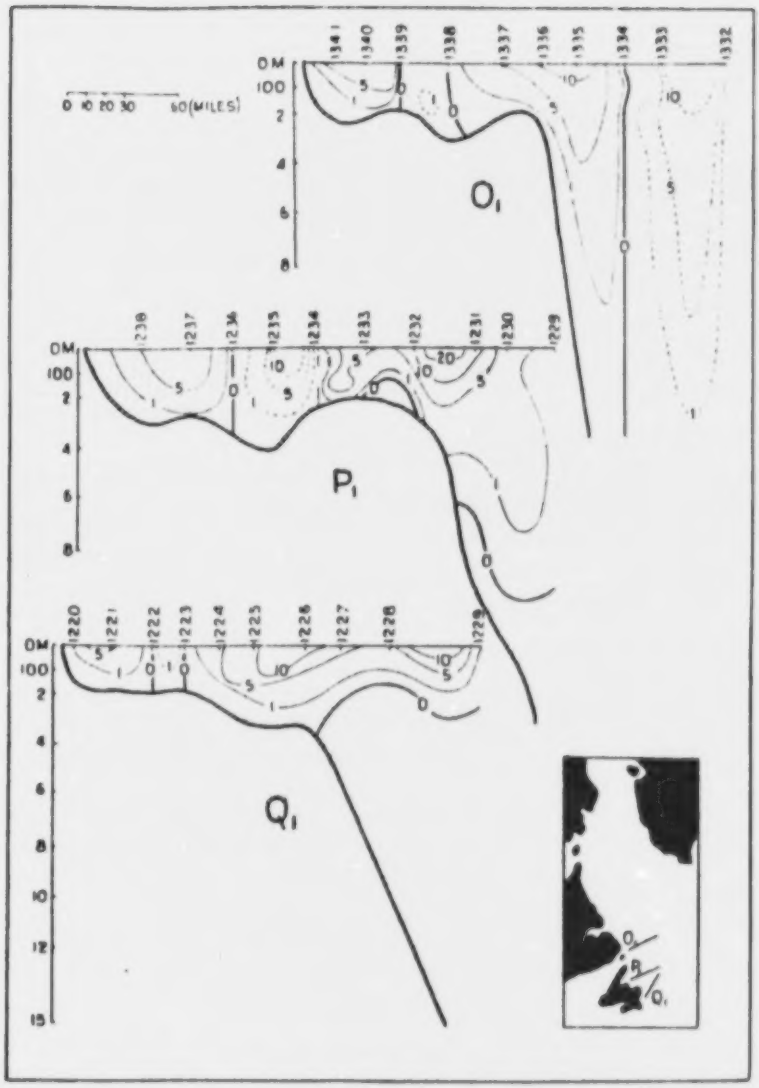


Fig. 11. Velocity profiles of the Labrador Current expressed in centimeters per second. The solid lines represent southerly current and the broken lines northerly current. Section O_1, August 7-8, 1931; Section P_1, July 6-7, 1931; and Section Q_1, July 4-6, 1931 (from Smith et al. 1937).

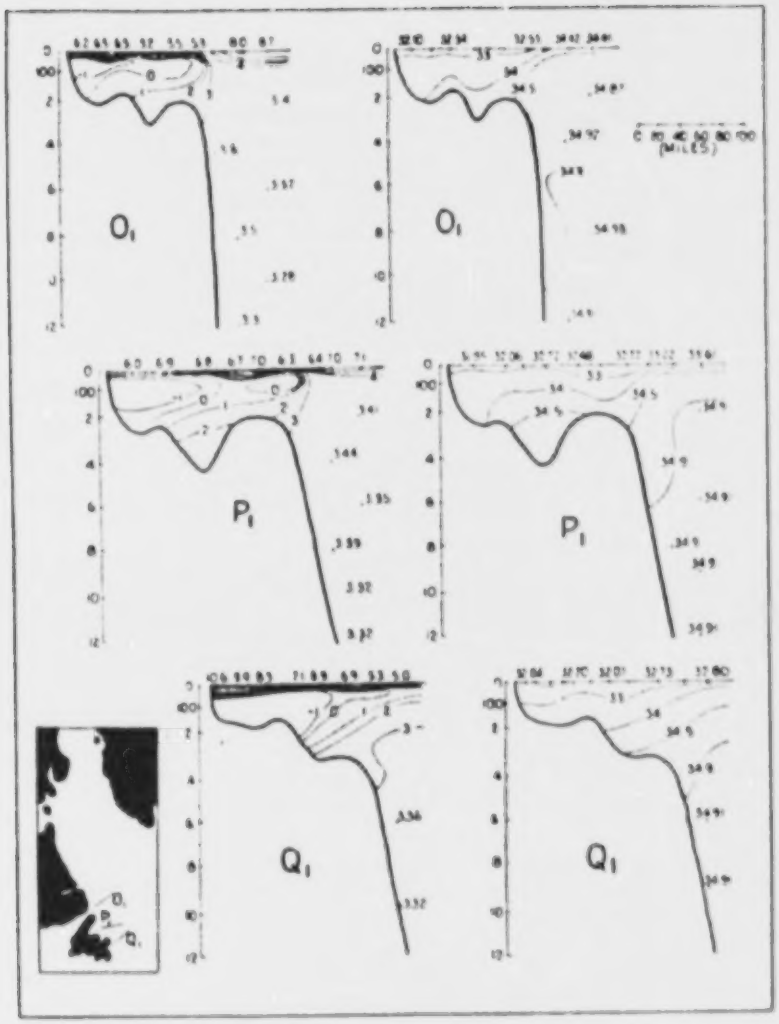


Fig. 12. Temperature and salinity profiles across the continental shelf and slope, July 4 to August 8, 1931. Section O_1, Belle Isle; Section P_1, White Bay; and Section Q_1, St. John's (from Smith et al. 1937).

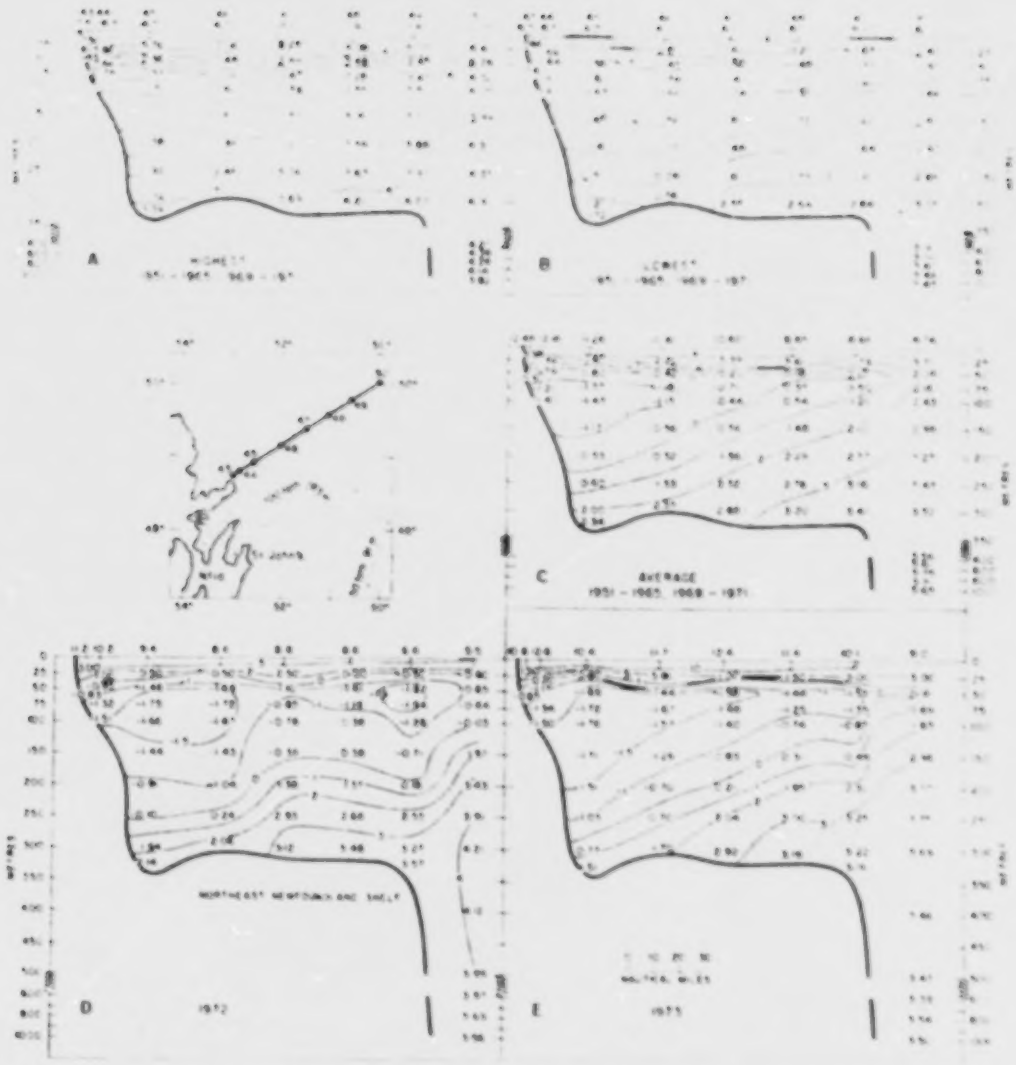


Fig. 13. Temperatures (°C) in section off Cape Bonavista: A - highest, B - lowest, and C - average, for the period 1951-1965, 1969-1971, July 23 to August 7, mean dates July 30-31; and D and E, for July 30-31, 1972, and July 29-30, 1973 (from Templeman 1975).

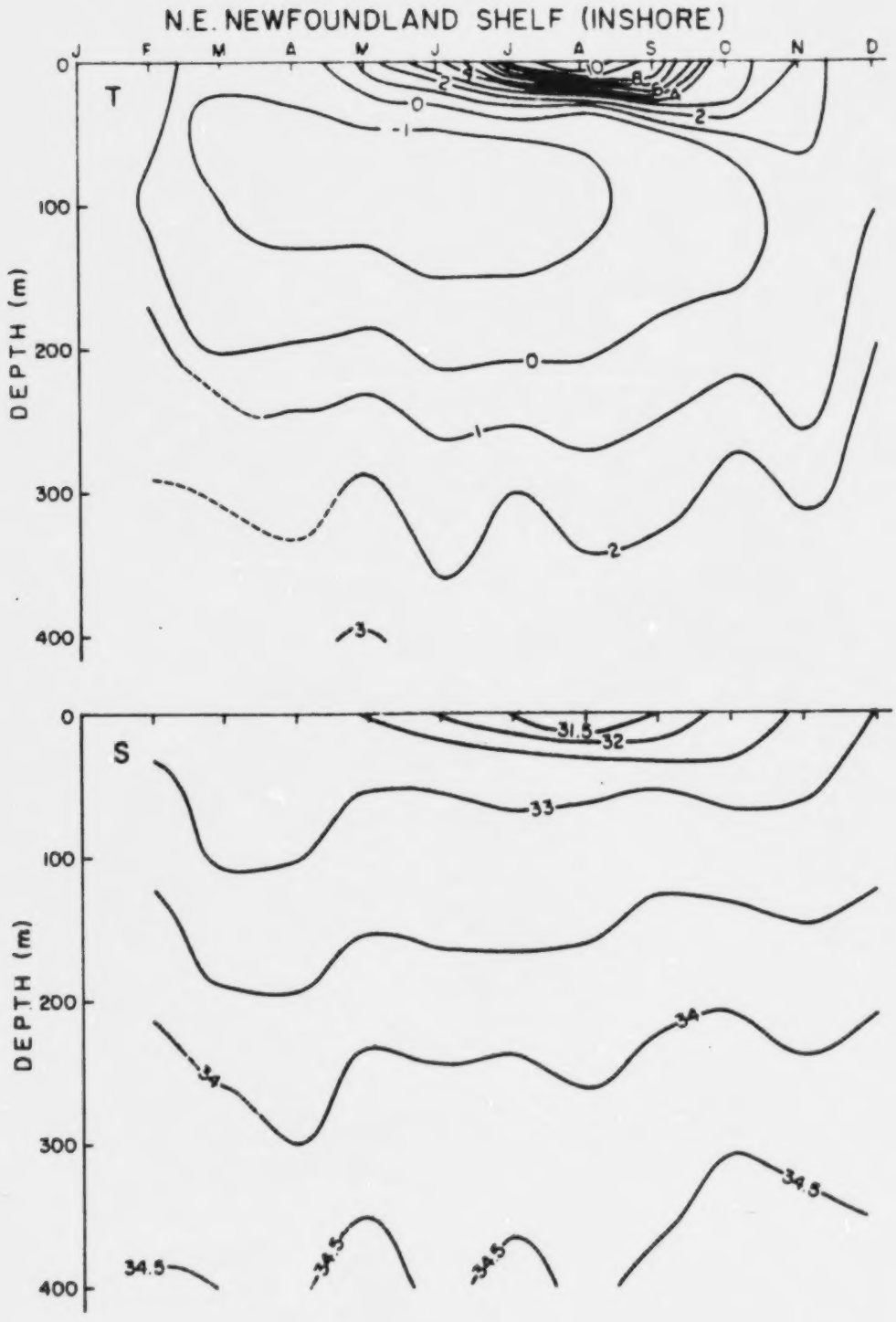


Fig. 14. The vertical distribution of the monthly mean temperature and salinity for Subarea 1 (see Fig. 16 for location), the northeastern Newfoundland Shelf (inshore) (from Drinkwater and Trites 1986).

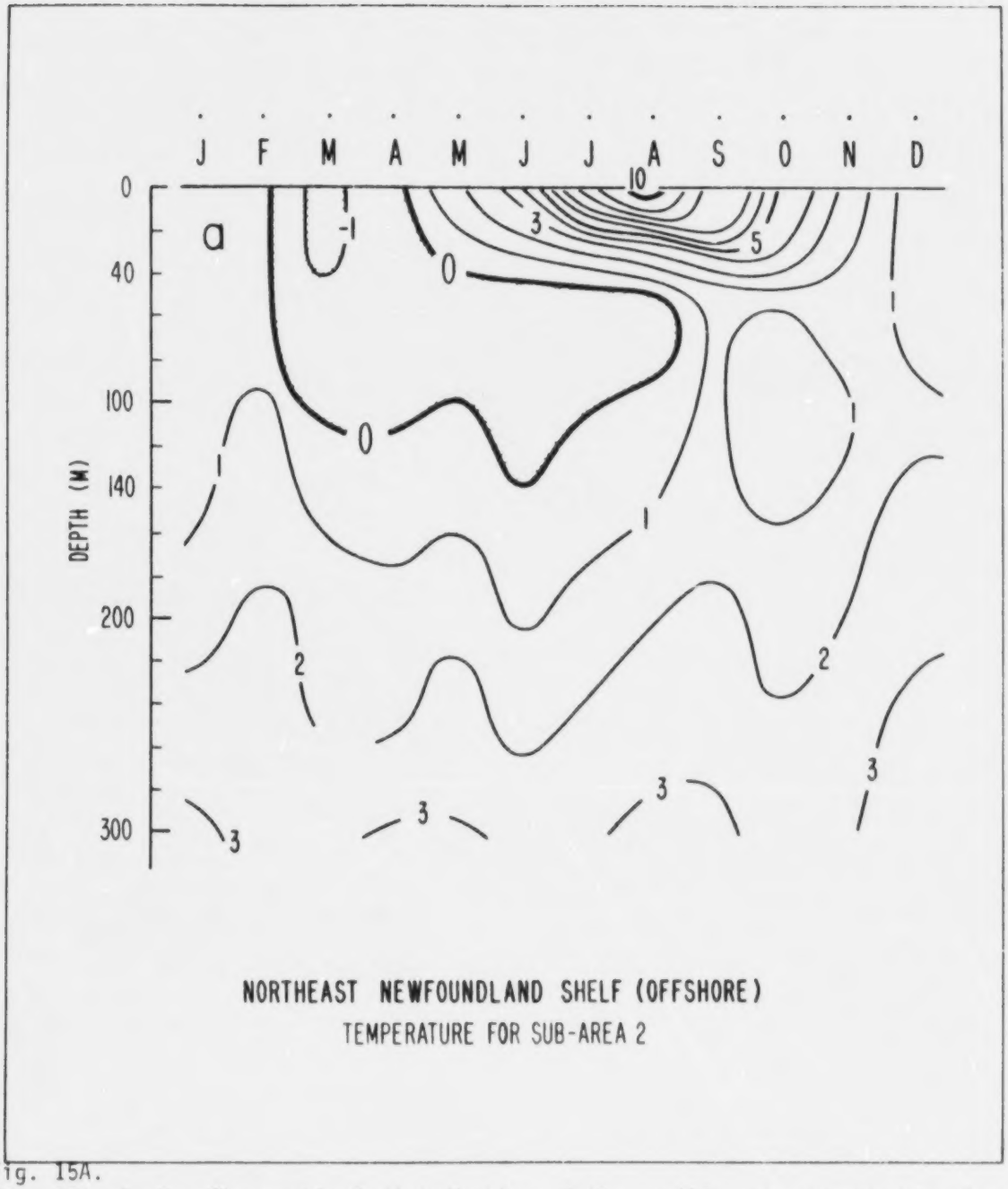
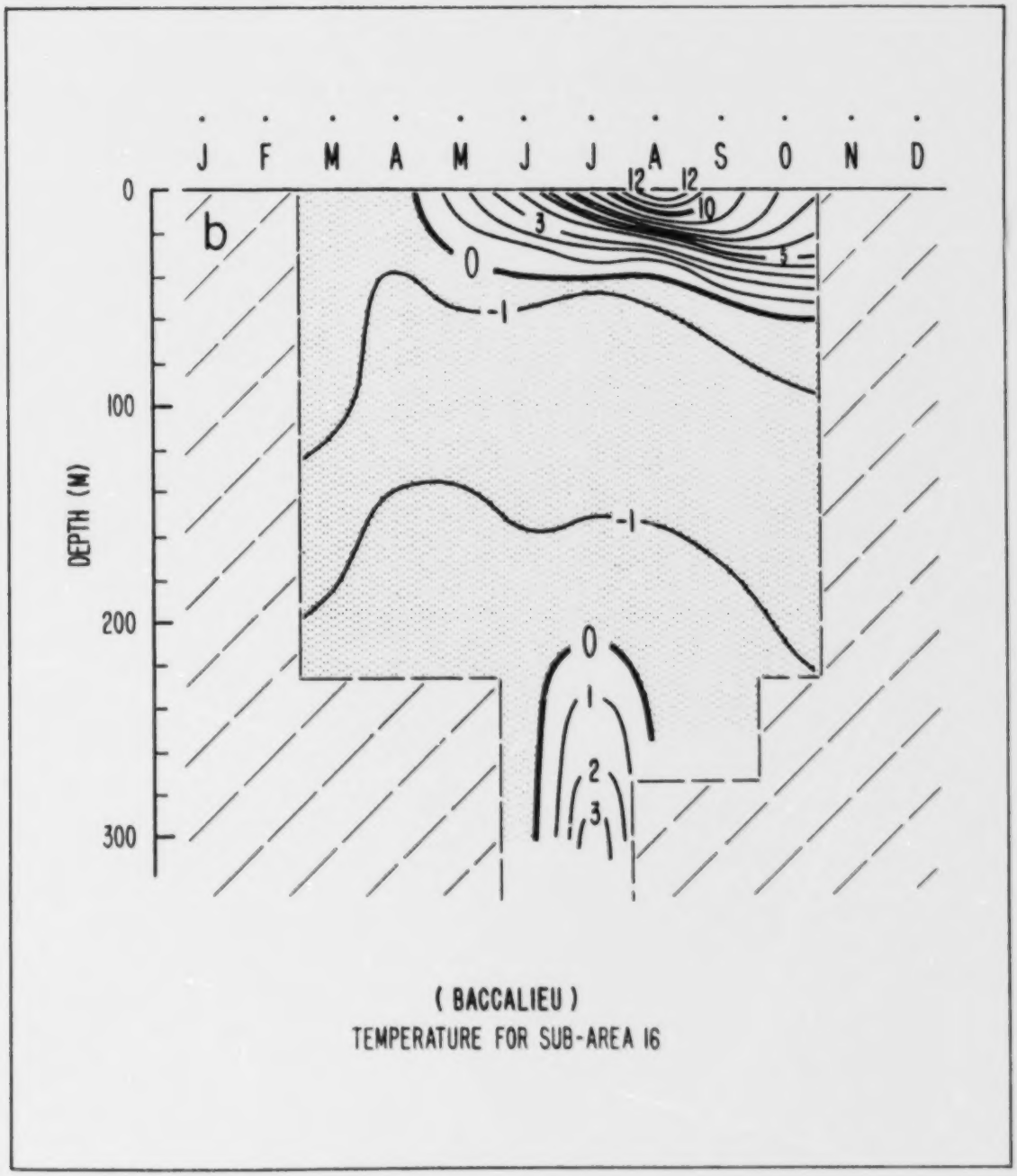


Fig. 15A.

Fig. 15A, B, C. The vertical distribution of the monthly mean temperature for:
15A) Subarea 2, the northeastern Newfoundland Shelf (offshore);
15B) Subarea 16, Saccalieu; and
15C) Subarea 15, northern slope (see Fig. 16) for locations.
The monthly mean values are taken from Drinkwater and Trites 1986.



(BACCALIEU)
TEMPERATURE FOR SUB-AREA 16

Fig. 15B.

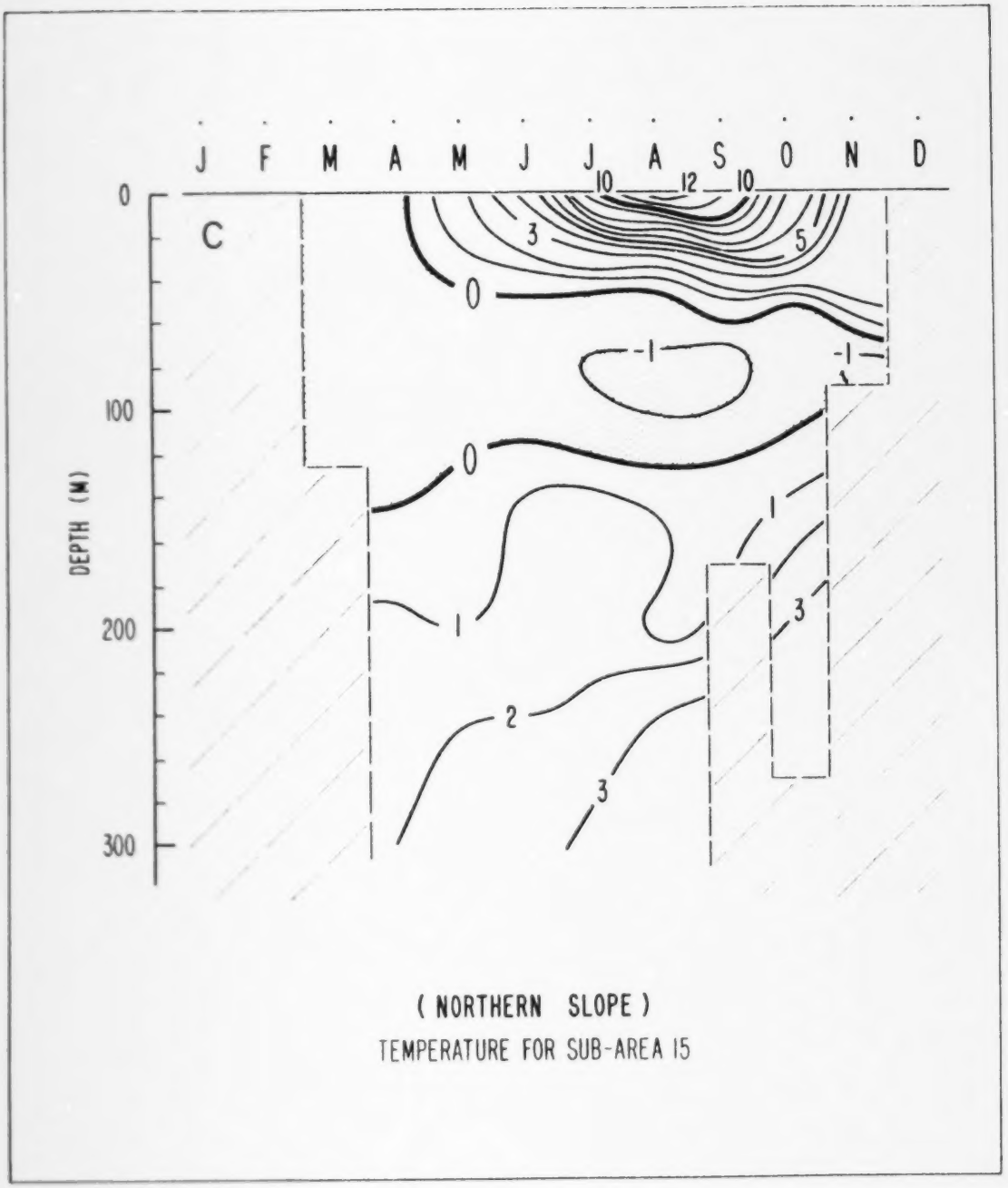
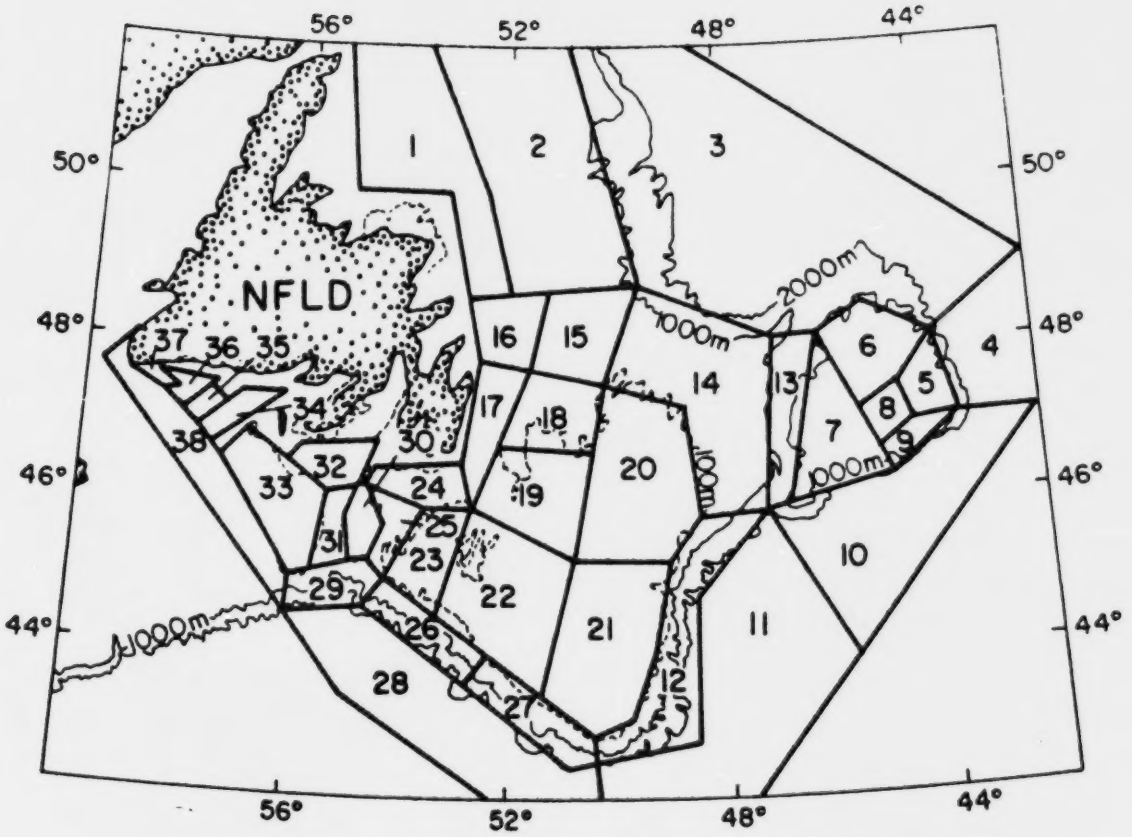

J F M A M J J A S O N D
0
100
200
300
DEPTH (M)
C
10
12
10
3
5
0
-1
-1
0
1
3
2
3
(NORTHERN SLOPE)
TEMPERATURE FOR SUB-AREA 15

Fig. 15C.



1	N.E. NEWFOUNDLAND SHELF (INSHORE)	20	NORTHEASTERN GRAND BAN
2	N.E. NEWFOUNDLAND SHELF (OFFSHORE)	21	SOUTHEASTERN GRAND BAN
3	LABRADOR BASIN	22	SOUTHWESTERN GRAND BAI
4	EASTERN OFFSHORE	23	WHALE BANK
5	FLEMISH CAP (EASTERN SLOPE)	24	SOUTHERN AVALON CHANNE
6	FLEMISH CAP (NORTHERN SLOPE)	25	HADDOCK CHANNEL
7	FLEMISH CAP (WESTERN SLOPE)	26	SOUTHWESTERN SLOPE
8	CENTRAL FLEMISH CAP	27	SOUTHERN SLOPE
9	FLEMISH CAP (SOUTHERN SLOPE)	28	SOUTHERN OFFSHORE
10	NORTHERN NEWFOUNDLAND BASIN	29	HALIBUT CHANNEL SLOPE
11	SOUTHWESTERN NEWFOUNDLAND BASIN	30	GREEN BANK
12	EASTERN SLOPE	31	HALIBUT CHANNEL
13	FLEMISH PASS	32	ST. PIERRE CHANNEL
14	NORTH EASTERN SLOPE	33	ST. PIERRE BANK
15	NORTHERN SLOPE	34	HERMITAGE CHANNEL
16	BACCALIU	35	BURGEO BANK
17	NORTHERN AVALON CHANNEL	36	BURGEO CHANNEL
18	NORTHEASTERN AVALON CHANNEL	37	ROSE BLANCHE BANK
19	NORTHWESTERN GRAND BANK	38	LAURENTIAN CHANNEL

Fig. 16. The Grand Banks of Newfoundland and adjacent regions, showing the subareas for which mean temperature and salinity were calculated (from Drinkwater and Trites 1986).

1. The thickness and seasonal duration of the cold intermediate layer are greater, and its minimum temperature is lower, in the inshore subareas.

2. The minimum temperatures in three of the four subareas occur below the surface in all months with available data, suggesting that advection (presumably from the north) plays a major role in the origin of the intermediate layer.

3. Temperatures below -1°C persist later into the fall in the southern subareas, consistent with advection from the north.

Further information on the latitudinal and seasonal variations of the cold intermediate layer is available from Keeley's (1981) summary by month of hydrographic properties on the Flemish Cap section across 47°, which shows that the layer adjoins the sea floor over the shallowing Grand Bank.

There is only limited information on the water column structure in the near-shore portion of the northeastern Newfoundland Shelf. The available moored measurements from Trinity Bay in summer (Yao 1986) reveal the occurrence of coastal upwelling and downwelling associated with along-bay wind stress variations, resulting in substantial variability in the depth of the thermocline and in coastal temperatures. There is also observational evidence of wind-driven upwelling and associated coastal sea-surface temperature variability in Conception Bay (e.g. Leggett et al. 1984; Taggart et al. 1987). These observations suggest that the upper extent of the cold intermediate layer (or equivalently, the depth of the thermocline) within about an internal Rossby radius (of order 10 km) of the coast in Trinity and Conception Bays in summer is strongly influenced by the along-bay component of wind stress, with the changes in layer position and hence temperature being of opposite sign on the Bays' opposite sides. The along-shore extent of the upwelling and downwelling (in particular, their occurrence in other bays and along open coastal areas), and the relative importance of local wind stress forcing versus Labrador Current forcing to variability in the cold intermediate layer are not known.

5.1.3. Some Hypotheses for Further Examination

A number of hypotheses for physical oceanographic influences on the availability of adult northern cod to the inshore Newfoundland fishery have been developed in the existing literature. These hypotheses can be grouped into influences on two stages of the cod's movement: influences on the route, timing and location of the inshore migration (e.g. Lear and Green 1984), and influences on the subsequent vertical position and location of the cod (e.g. Templeman 1966).

The leading hypothesis for a physical oceanographic influence on the inshore migration follows from Lear's and Green's (1984, p. 313) second strategy for their inshore migration,

> "Cod swim in over the banks under the cold intermediate layer until they reach a depth of about 150-200 m near the coast, where they encounter the cold-water barrier

> (0 to -1.5°C). If capelin were in the water column immediately above them, they might ascend into cold water in pursuit and follow the capelin migration into the inshore area in the upper layers."

More specifically, Lear et al. (1986) propose that the proportion of cod migrating inshore depends on two sets of factors,

> "The proportion migrating to shallow inshore water may vary with the temperature or thickness of the core of the Labrador Current. The proportion should increase with increasing temperature and decreasing thickness of the cold layer."
>
> "The proportion migrating inshore may vary with prey availability and distribution."

The former set of factors, sometimes referred to as the "thermal barrier" influence, may be taken as forming the leading hypothesis for a physical oceanographic influence on the inshore migration, with the underlying assumption being that the cod avoid waters with temperatures below about -0.5°C. Other, less-developed, hypotheses pertaining to the inshore migration are that it varies geographically associated with variations in the water column structure in bays and around headlands, and that it is related to the springtime and summertime current patterns on the northeastern Newfoundland Shelf.

The second group of hypotheses for physical oceanographic influences on the availability of cod to the inshore fishery is summarized by Templeman (1966) and illustrated in Figures 17 and 18. The underlying assumption of these hypotheses, which pertain to the vertical and cross-shelf positions of the cod after they have moved through or around the cold intermediate layer, is that the cod's preferred temperature range is above that of the intermediate layer but below the surface-water temperatures that usually develop in summer. The relevant physical oceanographic features are the depth and temperature structure of the summertime thermocline and warm surface layer in the near-shore region. Lear et al. (1986), who categorize this group of hypotheses as influences on catchability rather than availability, suggest that the important physical factors are the wind direction, wind strength, air temperature, sunlight, and current direction and strength. They also suggest that a second physical oceanographic influence on the cod's position is the light intensity which varies with cloud cover and fog.

5.1.4. Current Relevant Research

Recent, ongoing, and planned research relevant to the hypothesized physical oceanographic influences include statistical analyses and field observations on the northeastern Newfoundland Shelf by the Northwest Atlantic Fisheries Centre (NAFC) and field measurements in neighbouring areas and modelling studies by the Atlantic Oceanographic Laboratory (AOL).

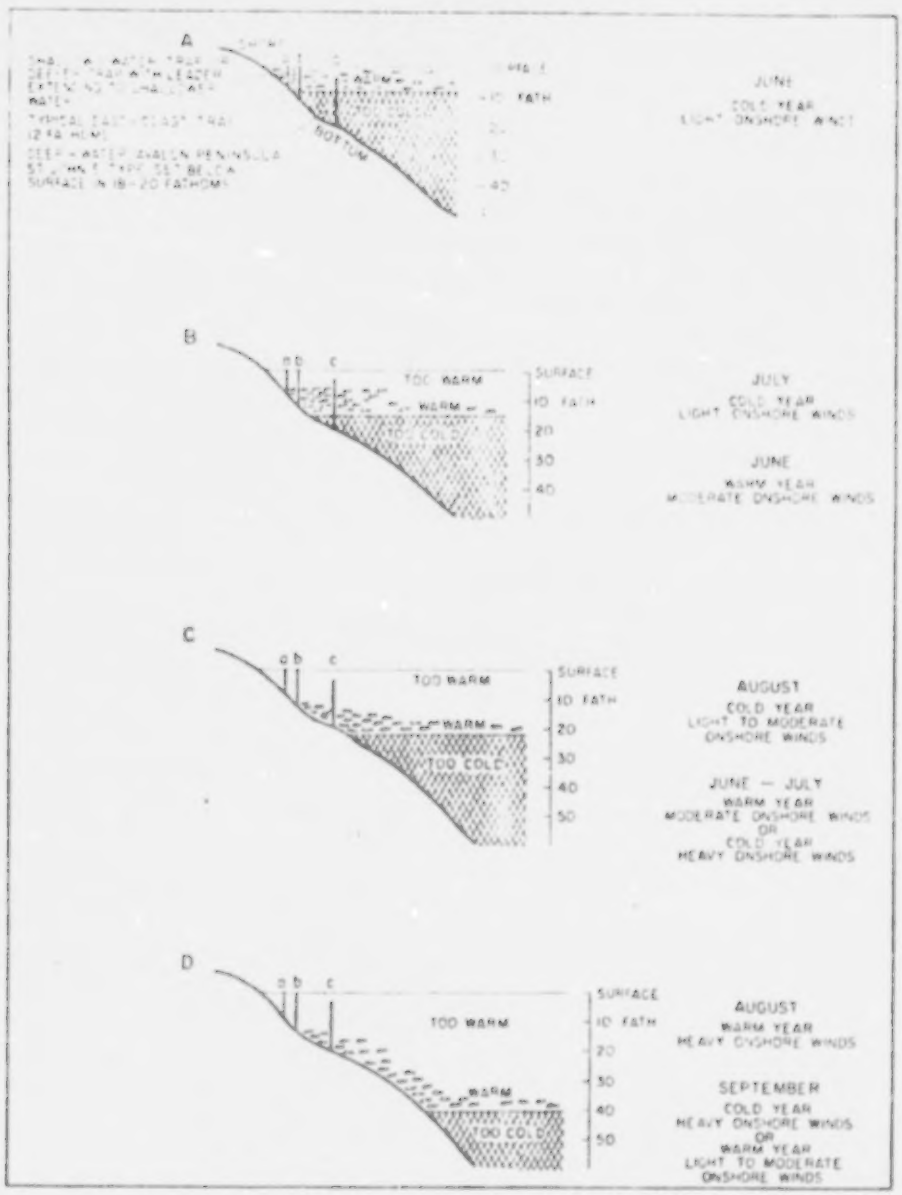


Fig. 17. Schematic representation of the variations in temperature conditions in various months on the east coast of Newfoundland, and their hypothesized effects on availability of cod to the trap fishery (from Templeman 1966).

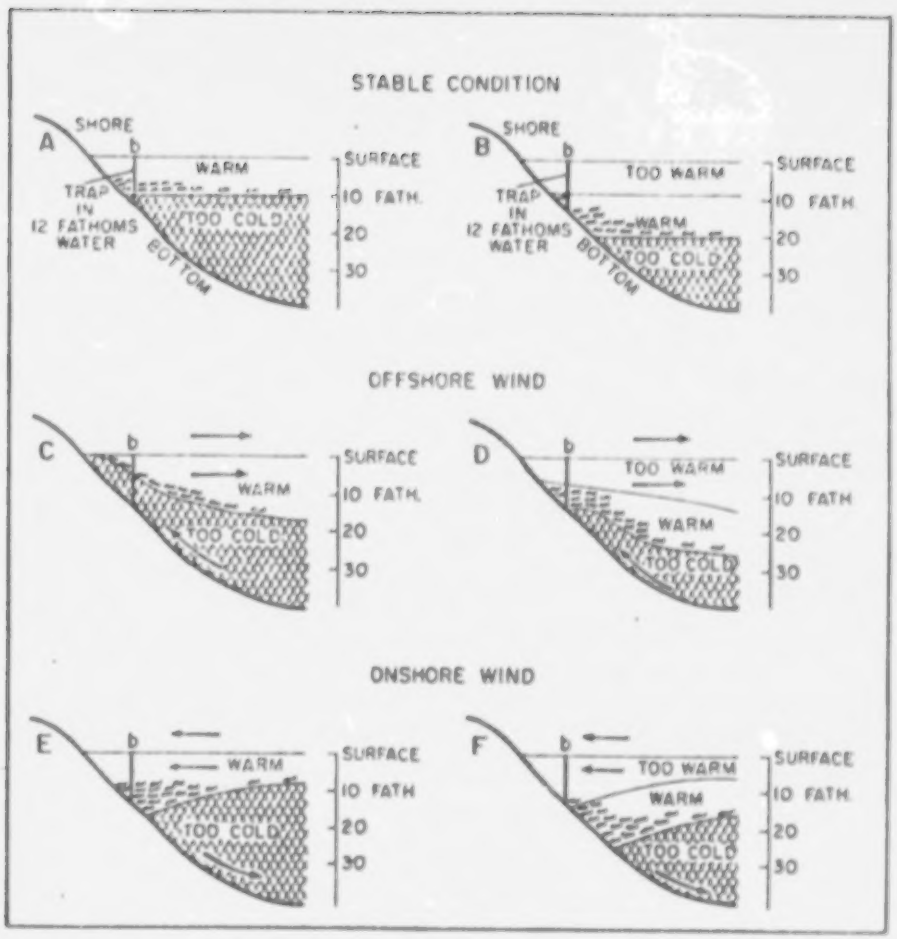


Fig. 18. Schematic representation of hypothesized effects of offshore and onshore winds on water layers and water temperatures on the east coast of Newfoundland, an on availability of cod to the trap fishery (from Templeman 1966).

Akenhead et al. (1982) used regression analysis to examine the relationship in the years 1972-79 between cod abundance indices (either inshore trap landings, total inshore landings, or indices for the availability of cod to inshore traps and to the total inshore fishery) and two indices of mature capelin biomass and one of summertime water temperature (the depth-average of the observations at Station 27). No significant correlations (at the 95% confidence level) were found for either the trap landings or total inshore landings, although the correlation between total inshore landings and temperature was positive (consistent with the leading hypothesis noted above) and significant at the 95% confidence level. There were also no significant correlations between the trap index and temperature or capelin biomass; but there was a significant positive correlation ($r = 0.81$) between the index of availability for the total inshore cod fishery and one mature capelin biomass index, and the r was increased to 0.91 with the addition of temperature to the regression. These results are supportive of the hypothesized thermal-barrier influence on inshore cod availability, although Akenhead et al. (1982) noted uncertainties in the data set which reduce the reliability of the results.

Lear et al. (1986) further examined the relationships between catch and environmental indices in the years 1975-84. They carried out a principal components analysis of the inshore landings data for three separate types of gear in the eight statistical (geographic) areas of eastern Newfoundland and Labrador, cod biomass abundance indices for two- to three-year-old capelin, surface- and intermediate-layer temperatures at Station 27, and the dates of ice-free conditions at Cape Freels and Cape Bauld. The analysis was done for both the gross catch data and the proportional catch data (gross catch divided by biomass). As the number of years of data did not substantially exceed the number of variables considered, the results of the analysis do not have statistical significance. Lear et al. (1986) argued that as similar relationships between the regional catches and the environmental indices were generally found for all three types of gear, the results indicate that there are some real associations between catch variability and environmental factors. The tendency was for increased inshore catches to be associated with warmer intermediate-layer and cooler surface temperatures - again supportive of the hypotheses above.

In addition to the continued annual (summertime) occupation of the historical cross-shelf hydrographic sections off Seal Island (across Hamilton Bank), Cape Bonavista, and St. John's (Flemish Cap section), the NAFC has recently initiated other physical oceanographic measurement programs of relevance to the hypothesized influences on northern cod availability (S.A. Akenhead, pers. comm., 1986). A large number of XBT observations are now being taken in the area of interest during fisheries patrols and fisheries research surveys. As an example, XBT observations taken during a hydroacoustic survey of cod distributions in June 1986 confirmed that the inshore-migrating cod are located immediately below the cold intermediate layer. In addition, moored measurements were made during the period May-September 1986 at three sites off eastern Newfoundland (Fig. 19): one off Cape Bonavista (current meter, thermistor chain, Ryan thermographs), and two in Trinity Bay (Ryan thermographs and current meter at one; thermistor chain at the other). The NAFC also has an ongoing temperature measurement program at various sites along the Newfoundland east coast in summer, using

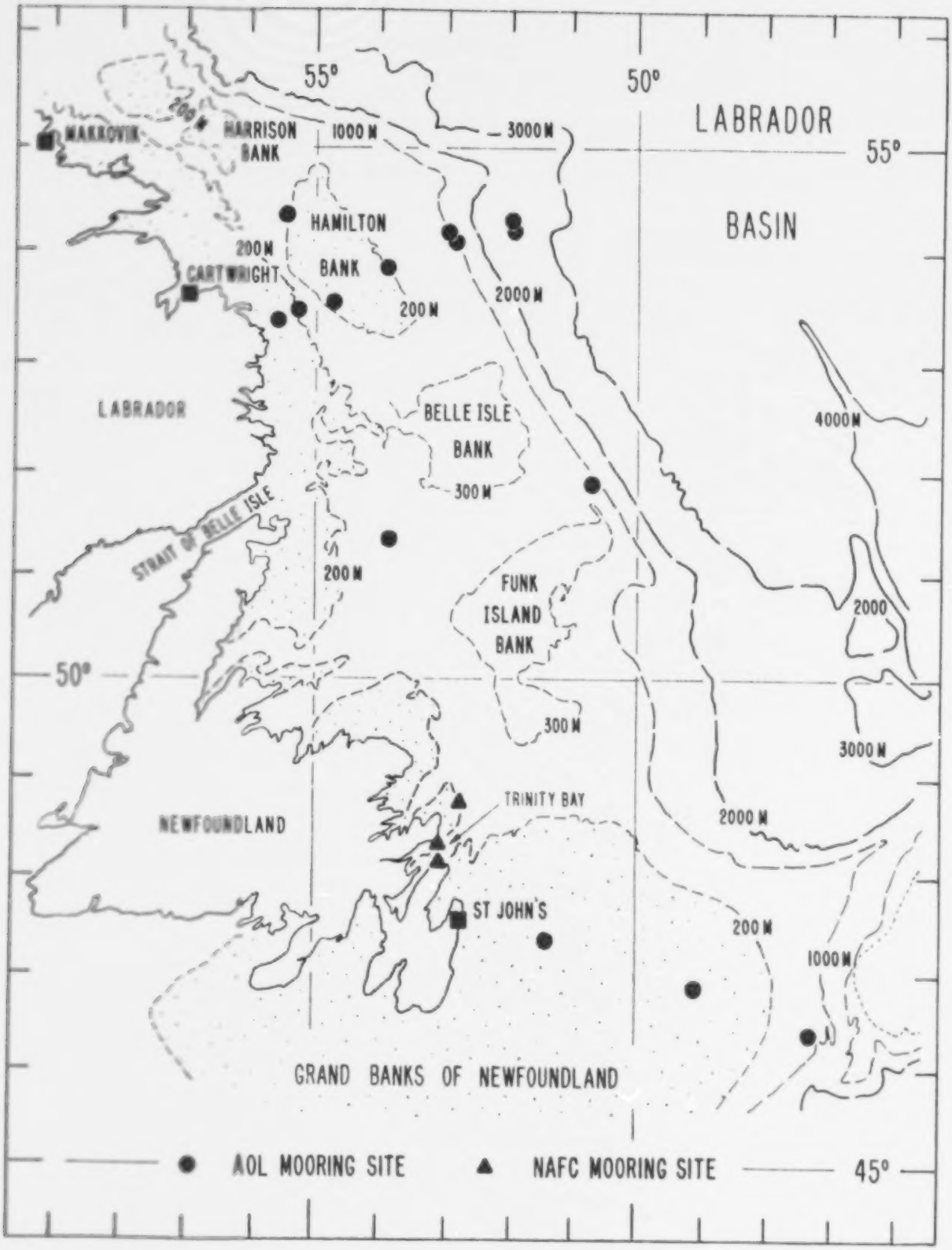


Fig. 19. AOL and NAFC mooring sites in NAFO Divisions 2J and 3KL.

moored Ryan thermographs, and is considering the initiation of XBT surveys on tracker aircraft flights over the Newfoundland Shelf.

AOL has been carrying out a long-term field study of variability in the Labrador Current since 1978, primarily involving moored measurements and hydrographic surveys in the Hamilton Bank area. During 1985-1986, current meter moorings were in place at three cross-shelf positions, and an expanded program involving current meter and/or bottom pressure gauge moorings at additional locations in the Hamilton Bank area and to the south is being carried out in 1986-87 (see Fig. 19 for locations). The expanded program is intended to determine the cross-shelf structure and seasonal variability of the Labrador Current on the southern Labrador Shelf and the relationship of variability in the current off Belle Isle and on the northern Grand Bank to variability upstream. It is intended that 1987-88 will be the last year of the long-term field program (J.R.N. Lazier, pers. comm.).

Shorter-term moored measurements of relevance to the hypothesized physical oceanographic influences on northern cod availability have been made by AOL in several other areas. An observational study of the inshore branch of the Labrador Current in the Avalon Channel was carried out during the period June 1980-April 1981 using moored current meters and a thermistor chain. These observations are described and interpreted in a recent doctoral thesis (Anderson 1986). Moored current measurements were made at five sites on Belle Isle Bank in June-October 1981 in a joint AOL/Petro-Canada program (Lazier et al. 1986), although an analysis of the observations has not been reported. AOL has recently initiated an observational study of the surface mixed layer in the Hibernia region of the northern Grand Bank, including moored measurements during the period April-October 1986. It is anticipated that there will be another field component of the study in 1988 (C.L. Tang, pers. comm., 1986).

A springtime field study of the surface mixed layer near the southern edge of the seasonal ice cover on the northeastern Newfoundland Shelf is currently being planned with AOL participation (Tang, personal communication, 1986). A pilot field program of this Labrador Ice Margin Experiment (LIMEX) took place in the spring of 1987, and an extended field program is expected to take place in a later year.

Theoretical and numerical modelling studies are being carried out by AOL in support of the long-term study of Labrador Current variability and as part of a study of the variability of sea ice extent on the Labrador and Newfoundland Shelves. These include a barotropic numerical model study of the flow on the Newfoundland Shelf associated with a southward flow across the model's northern boundary (Greenberg and Petrie, in prep., 1987) and a numerical model investigation of sea ice growth, deformation, and decay. The latter model and correlation analysis are being used to identify the contributing factors to variability in the observed sea ice extent during the period 1963-85, using a time series derived from ice distribution charts.

Finally, a recent analysis (Loucks et al. 1986; Thompson et al. 1987) of sea-surface temperature variability between Cape Hatteras and Greenland

during the period 1946-80 indicates that temperature anomalies have large space scales (order 1,000 km) and are generally established in winter and persist through spring. The authors suggest that these features are consistent with wintertime meteorological forcing, with positive temperature anomalies being associated with anomalous onshore winter winds and hence decreased latent and sensible heat fluxes from the ocean. The implication of these results is that the properties of the cold intermediate layer on the northwestern Atlantic shelf in any given year may be largely determined by meteorological and other factors (e.g. ice cover) affecting air-sea exchange during the preceding winter.

5.1.5. Comments and Recommendations

1. Fisheries scientists have used the available physical oceanographic information from the northeastern Newfoundland Shelf to formulate a number of plausible hypotheses for oceanographic influences on the availability of northern cod to the Newfoundland and Labrador inshore fishery.

2. The analyses to date of oceanographic and cod catch data provide some support for the leading hypothesis but have not determined with statistical confidence the validity of the hypothesized physical oceanographic influences on cod availability.

3. The available physical oceanographic information from the immediate area of interest comes primarily from hydrographic data. The hypothesized influences, however, may be associated with large-scale variability in the Labrador Current and the hydrographic structure of the Labrador and Newfoundland Shelves, which has been the subject of a major AOL field effort since 1978, focused on the Hamilton Bank area of the Labrador Shelf. Thus, existing moored measurements from the Hamilton Bank area, Avalon Channel, the Hibernia region, and Trinity Bay are of relevance to the northern cod availability problem.

4. The AOL investigation of variability in sea ice extent on the Labrador and Newfoundland Shelves is also of relevance to the northern cod availability problem.

5. A physical oceanographic research program aimed at describing, and determining the contributing factors to, the cross-shelf and along-shelf structure and the seasonal and interannual variability of the cold intermediate layer on the northeastern Newfoundland Shelf would be of relevance to the leading hypothesis (the "thermal-barrier" hypothesis) for an oceanographic influence on the availability of cod to the Newfoundland inshore fishery. This program could involve the following.

   A. Analysis of the existing hydrographic data from the Hamilton Bank, White Bay, Cape Bonavista, and St. John's (47°N) sections to obtain a quantitative description of the seasonal, interannual, and along-shelf variability in the cross-shelf structure of the cold intermediate layer

B. Analysis of the existing time series of hydrographic data from the Hamilton Bank area and Station 27 to examine their representativeness of seasonal, interannual, and along-shelf variability in the cold intermediate layer; and the roles of advection, ice cover and local wintertime atmospheric forcing in contributing to this variability

C. Moored current, temperature, salinity, and bottom pressure measurements at several cross-shelf positions on the Bonavista section for at least the spring-autumn period of a few years, aimed at describing the current and hydrographic variability (particularly of the cold intermediate layer) and determining its relation to variability in the Hamilton Bank and northern Grand Bank (47°N) areas

D. Additional moored measurements of current, temperature, and salinity on the cross-shelf line off Belle Isle where AOL currently has moorings in place (Fig. 19) or the White Bay section, aimed at providing additional information on along-shelf variability

E. Moored current, temperature, and salinity measurements at the previously occupied sites in Trinity Bay, aimed at obtaining further information on the relative importance of local wind-driven upwelling versus fluctuations in the Labrador Current and in the cold intermediate layer on the shelf to variability in the hydrographic properties in Trinity Bay

F. Monthly XBT observations during the spring-autumn period on the cross-shelf section off Cape Bonavista and possibly on the sections off St. John's, White Bay, and Belle Isle

G. Ryan thermograph observations during the spring-summer period at various coastal sites along the eastern and northeastern coasts of Newfoundland, aimed at determining the significance of variability in the cold intermediate layer to coastal temperatures

It is recommended that the analysis of existing data (A, B) be given first priority, and that any field study be designed on the basis of the results of that analysis, advice from scientists presently conducting the field studies of Labrador Current variability, and the considerations and suggestions outlined here. A field study along the lines of that outlined above, if carried out during the long-term AOL study, would provide the potential for linking together the following studies and data sets: the current XBT and Ryan thermograph observational programs of NAFC, the current NAFC moored measurements, the long-term AOL study of Labrador Current variability, the previous moored measurements in Trinity Bay, and the historical hydrographic data collected on the Bonavista and other cross-shelf sections. It would not only provide a description of the variability in currents and water mass roperties on one part of the inner northeastern Newfoundland Shelf and in one major bay on the Newfoundland east coast, but would also allow hypotheses regarding the relative importance of local wind-driven upwelling and larger-scale Labrador Current fluctuations to this variability to be examined.

6. The mooring component of the program outlined in 5 may be constrained by the combined influences on moored gear survival of the seasonal ice cover (including icebergs) and fishing pressure.

7. The research program outlined in 5 should also provide background physical oceanographic information of relevance to the second group of hypothesized influences on cod availability, namely regarding the structure of the thermocline and warm surface layer along the eastern and northeastern coasts of Newfoundland. Furthermore, if the field program were conducted concurrently with the LIMEX field program, relevant information on the significance of sea ice to the upper water column structure in the area of interest would also be available.

8. The research program outlined in 5 should be complemented by the development and examination of conceptual models for the formation and evolution of the cold intermediate layer and for the response of the inner northeastern Newfoundland Shelf to wind stress forcing. The cold intermediate layer could be examined in relation to existing conceptual models for the intermediate layer in the Gulf of St. Lawrence and for the cold pool in the Gulf of Maine and Middle Atlantic Bight. The response to wind stress forcing could be examined using idealized one- and two-layer models for bays of various geometries adjoining a continental shelf. It is recommended that these models be developed prior to any major field program so that they can be used in the detailed experimental design and formulation of specific physical oceanographic hypotheses.

9. Satellite infrared imagery can provide valuable synoptic information on the surface temperature distribution in the area of interest, particularly of the occurrence of coastal upwelling, and hence should be used to complement any field study.

10. It is recommended that any physical oceanographic field program along the lines of that suggested above also be complemented by concurrent hydroacoustic surveys and tagging experiments aimed at describing the extent, route, and timing of the migration of northern cod in relation to the description of the physical environment.

11. Any physical oceanographic investigation of the cold intermediate layer should also be used to identify a long-term monitoring strategy of the layer's features that are considered to influence the availability of northern cod.

12. It is probable that the properties of the cold intermediate layer which are hypothesized to influence the northern cod migration are determined by atmospheric and oceanographic conditions during the preceding winter, in which case a degree of useful predictability may be possible.

13. The research program outlined above would also be relevant to the variability of the relatively warm water underlying the cold intermediate layer and hence to the northern cod's spawning. Furthermore, inshore intrusions of this water mass affects the general oceanographic conditions at depth in the bays on the Newfoundland east coast and hence possibly the distribution of a number of species.

14. The parallel fisheries research requirements have not been considered in detail. Attention, however, should be drawn to the dismal state of our knowledge on the fine structure of cod distribution on the offshore banks of Areas 2J, 3K, and 3L in the winter/spring period. It would be instructive to undertake a survey of the offshore areas at a time when most of the cod can be expected to be inshore.

5.2. AVAILABILITY OF SILVER HAKE ON THE SCOTIAN SHELF

5.2.1. The Fisheries Problem

Silver hake (Merluccius bilinearis) is an important demersal resource for fleets fishing on the Scotian Shelf within Canada's 200-mile limit, with the catch taken by the USSR, Cuba, and Japan in 1985 exceeding that of any other species of the Shelf (Showell and Waldron 1986). This fishery, which occurs in April to June, has been restricted since 1977 to an area seaward of what is known as the Small Mesh Gear Line (SMGL) which runs along the edge of the shelf roughly along the 100 m isobath between the Gully east of Sable Island and Northeast Channel (Fig. 20). At this time and location, a large fraction of the Scotian Shelf stock of silver hake, which has a preferred temperature range of 7-10°C (Scott 1982), is overwintering at depths of about 200 m before initiating a late-spring-early-summer migration to spawn in the vicinity of banks on the Shelf. The concentrations of overwintering hake are highest to the south of Sable Island, and it is believed that one of the primary routes for the on-shelf migration is through the Scotian Gulf to the west. A smaller fraction of the stock is known to overwinter at depth in the deep basins on the Shelf, particularly in Emerald Basin.

It has been suggested (e.g. Garcia 1981; Showell and Waldron 1986) that the timing of the spawning migration of the silver hake that overwinter along the shelf edge may depend on the seasonal warming of the shelf waters shoreward of the SMGL and of the waters along the shelf edge, either through a direct temperature influence or a temperature effect on the silver hake's maturation. Investigation of these suggested influences is considered to be particularly important because the commercial catch rates on the pre-spawning aggregations south of the SMGL are currently used as the index of stock abundance. There is concern that this index may be biased by interannual variability in the water temperature through its influence on the length of time that the silver hake remain available to the fishery south of the SMGL.

Understanding the factors affecting the on-shelf migration of silver hake is also considered important because of growing interest in opening a silver hake fishery on the Scotian Shelf as a result of the stock's increasing size. In addition to the suggested temperature influence on the timing of the migration, it has been suggested (e.g. Scott 1976; Garcia 1981) that the location of silver hake on the Shelf is dependent on the occurrence of bottom water with temperature in the hake's preferred range. This second "availability" question will not be dealt with further here.

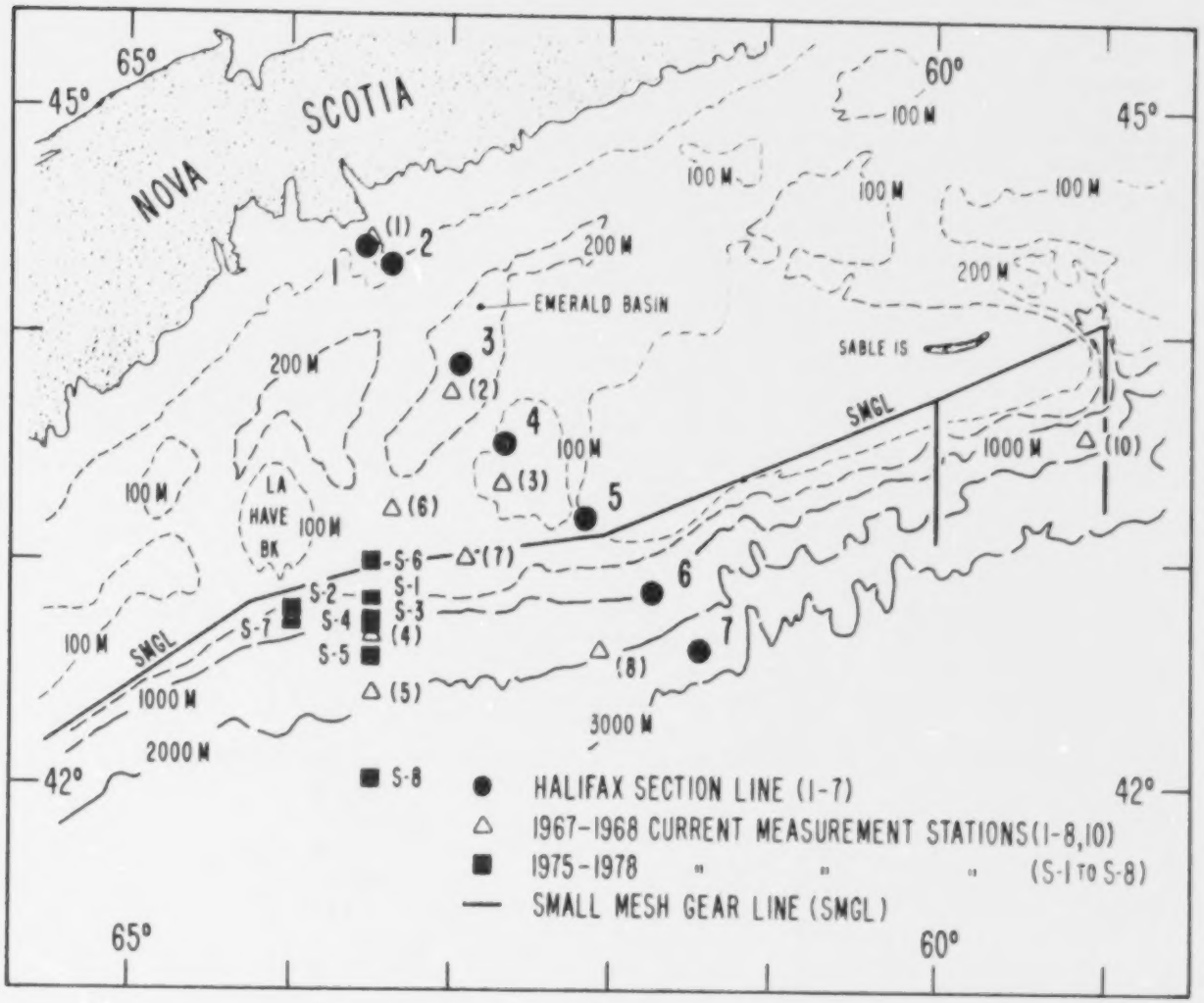


Fig. 20. Location of Halifax section stations, 1967-68 and 1975-78 current measurement stations, and small mesh gear line (SMGL).

5.2.2. Background Physical Oceanography

The following is a brief summary of the available physical oceanographic information from the outer Scotian Shelf and Slope.

The vertical distribution of water masses on the Scotian Shelf can be described from observations taken along the Halifax Section (Fig. 20) approximately once per season between 1950 and 1977, and summarized by Drinkwater and Taylor (1982). Figures 21-23, from Drinkwater and Taylor (1982), show the average distributions of temperature, salinity, and density for the months of March, May, and July, respectively. As discussed by Hachey (1942), McLellan (1954), Smith et al. (1978), and others, the water mass structure over the Shelf generally evolves seasonally from a wintertime two-layer state with relatively cool and freshwater of Gulf of St. Lawrence and Labrador Current origin modified by winter cooling and mixing, overlying warmer and more-saline water derived primarily from on-shelf intrusions of slope water. With springtime and summertime solar heating and the advection of low-salinity surface water from the Gulf of St. Lawrence, a warm and relatively fresh surface layer develops in spring and persists until autumn, resulting in a three-layer structure with a temperature-minimum layer at intermediate depths. The so-called "coastal water" (wintertime upper layer and summertime upper and intermediate layers) extends across the shelf break and over the continental slope in the upper 100 m or so, overlying two types of slope water (Gatien 1976; Fig. 24): Labrador slope water, usually found adjacent to the shelf break with temperatures in the approximate range of 6-10°C in the upper 500 m; and warm slope water, usually found further offshore with temperatures generally above 10°C. Thus, the waters with temperature in the silver hake's preferred range are:

1. In winter, water of slope water origin at depths below about 100 m on the Shelf, particularly in the deep basins, and Labrador slope water along the shelf edge and upper slope

2. In spring and summer, the waters named above plus a thin layer in the thermocline at about 25 m depth over most of the shelf and water extending from the thermocline to the sea floor over parts of the offshore banks

It should be noted, however, that there is considerable variability about the average distributions in Figures 21 to 23. For example, Drinkwater and Taylor (1982) report standard deviations of 0.94°C for the average March temperature (7.07°C) at 150 m (the depth of maximum temperature) at Station 3 in Emerald Basin, 2.43°C for the average July temperature (5.19°C) at 75 m (the maximum standard depth) at Station 5 on western Sable Bank, and 2.66°C for the average May temperature (8.86°C) at 125 m (the depth of maximum temperature) at Station 6 on the continental slope (see Fig. 20 for locations).

The horizontal extent of the bottom water with temperature in the hake's preferred range has not been described using the available climatological data base, but the bottom temperature distribution has been presented for some individual surveys (e.g. McLellan 1954; Scott 1976). As an example, Figure 25 shows the bottom temperature distribution during a groundfish survey on the Scotian Shelf from June 29 to July 22, 1981. A tongue of

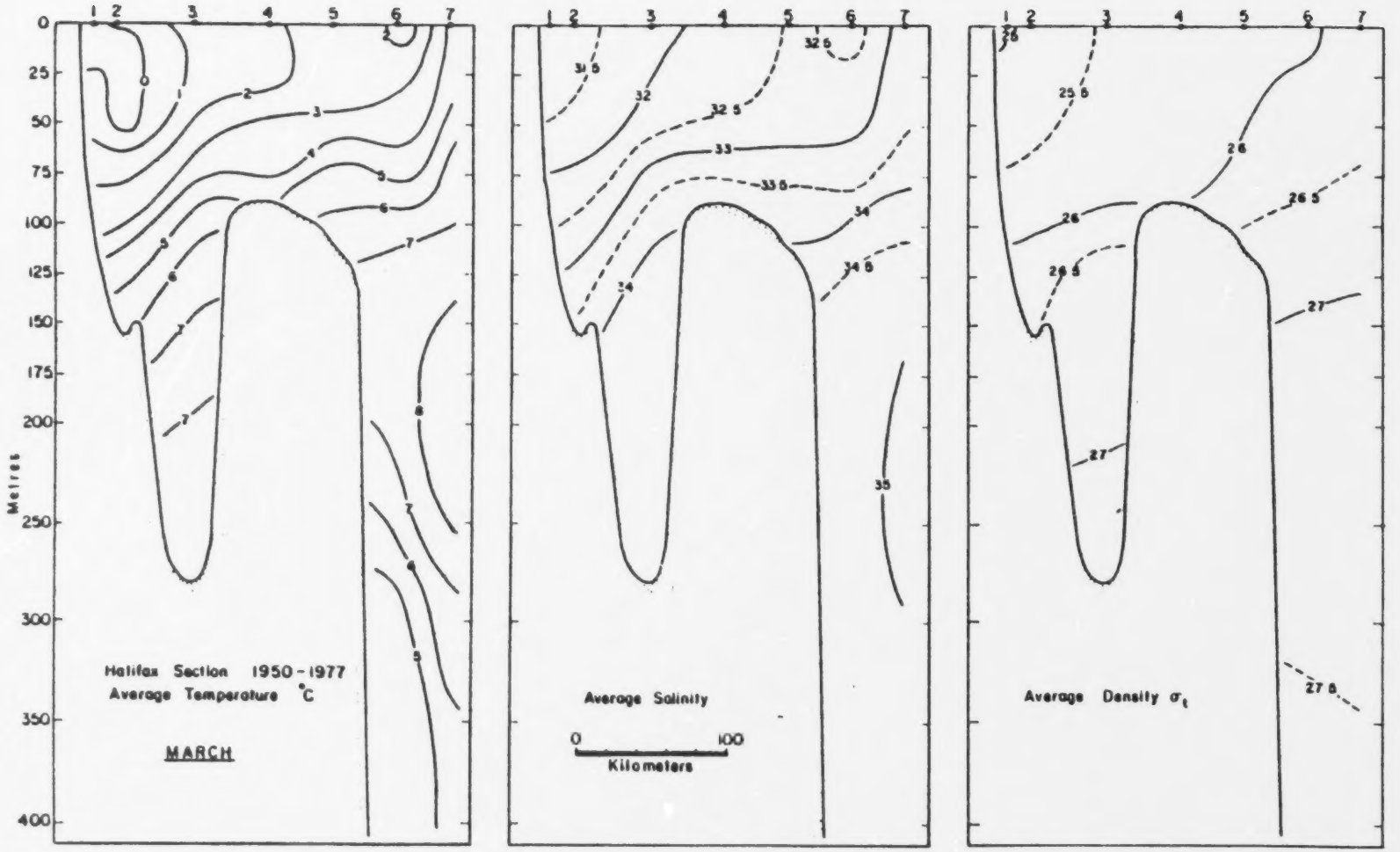


Fig. 21. The mean temperature, salinity, and density along the Halifax section during March (from Drinkwater and Taylor 1982).

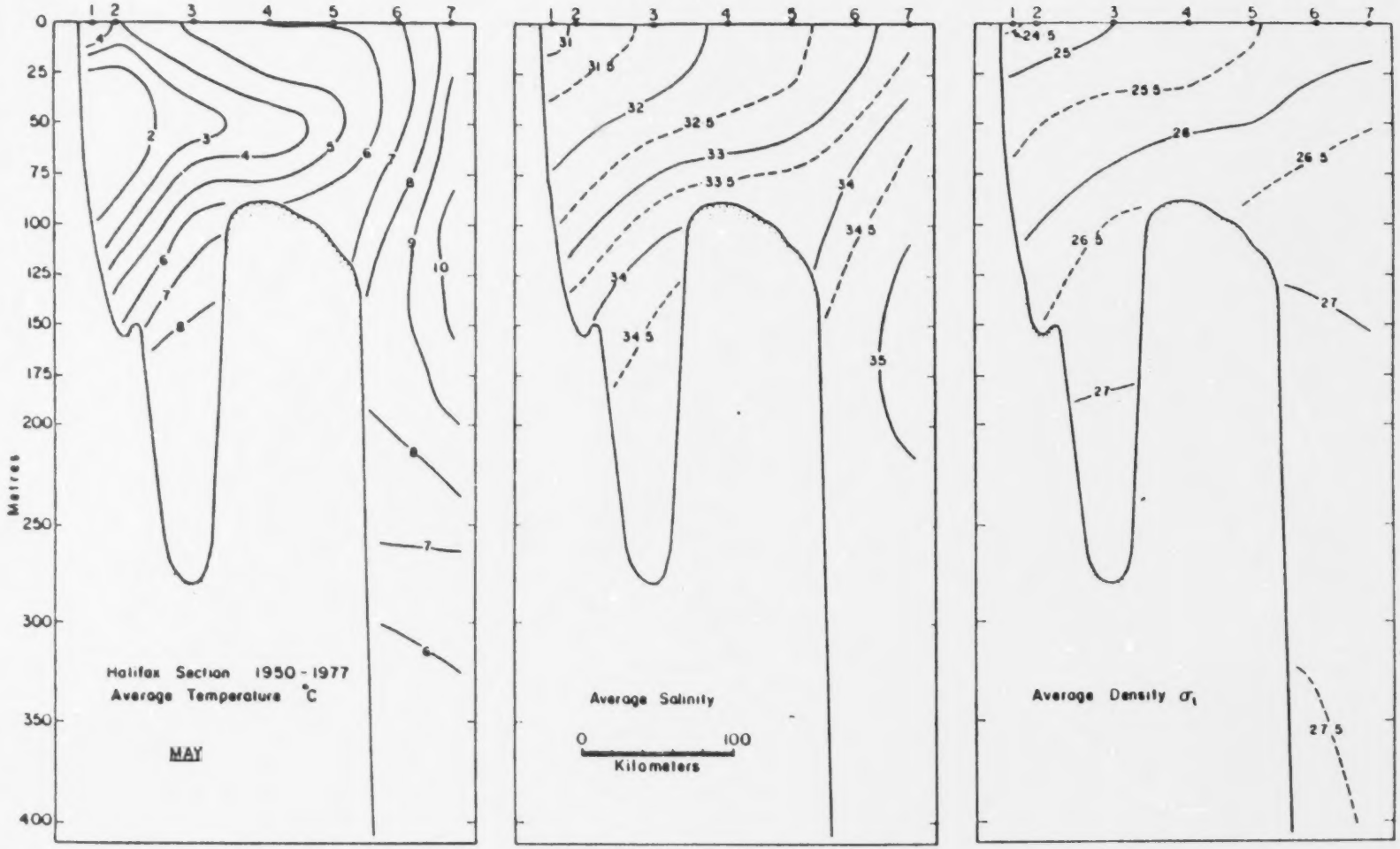


Fig. 22. The mean temperature, salinity, and density along the Halifax section during May (from Drinkwater and Taylor 1982).

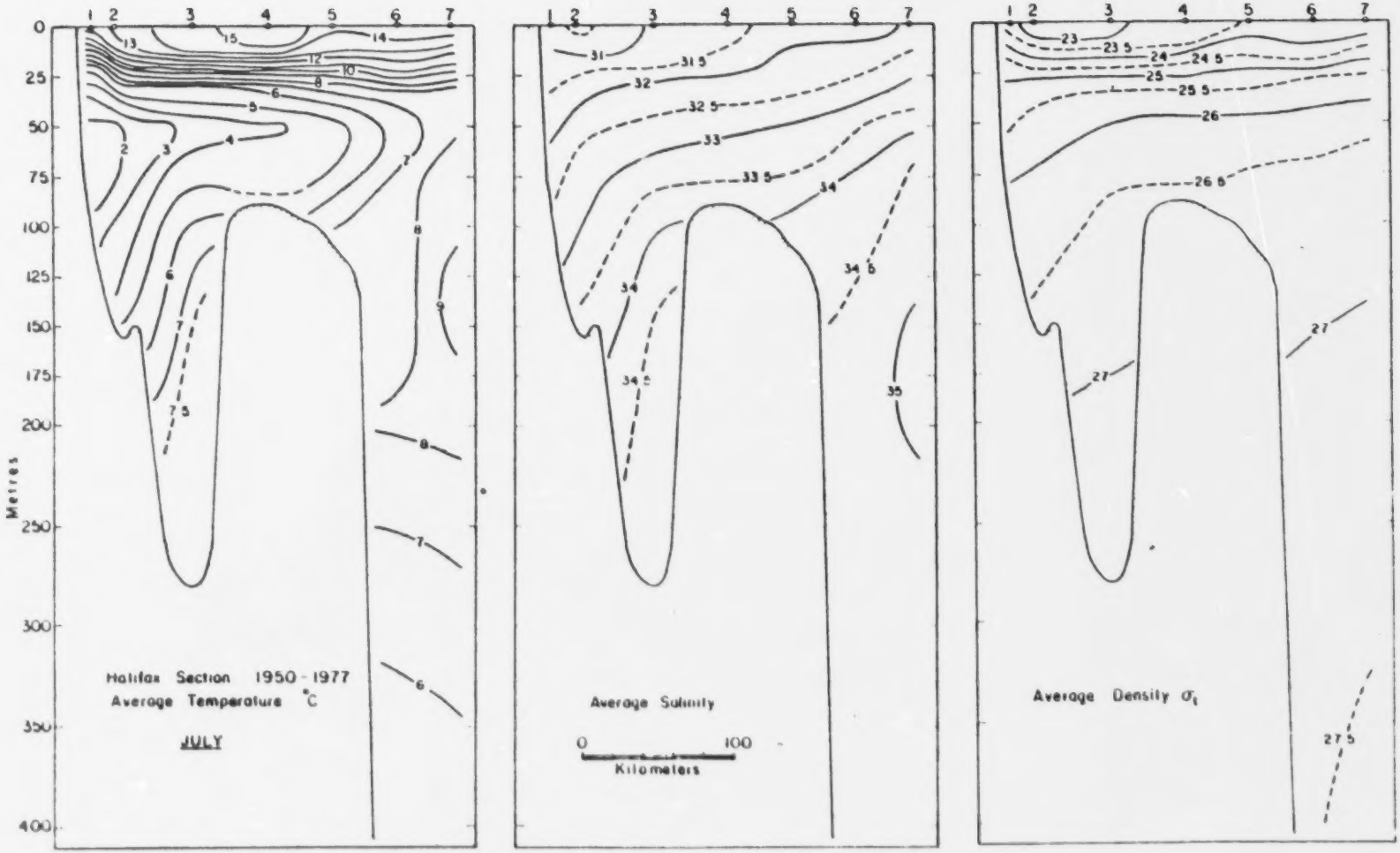


Fig. 23. The mean temperature, salinity, and density along the Halifax section during July (from Drinkwater and Taylor 1982).

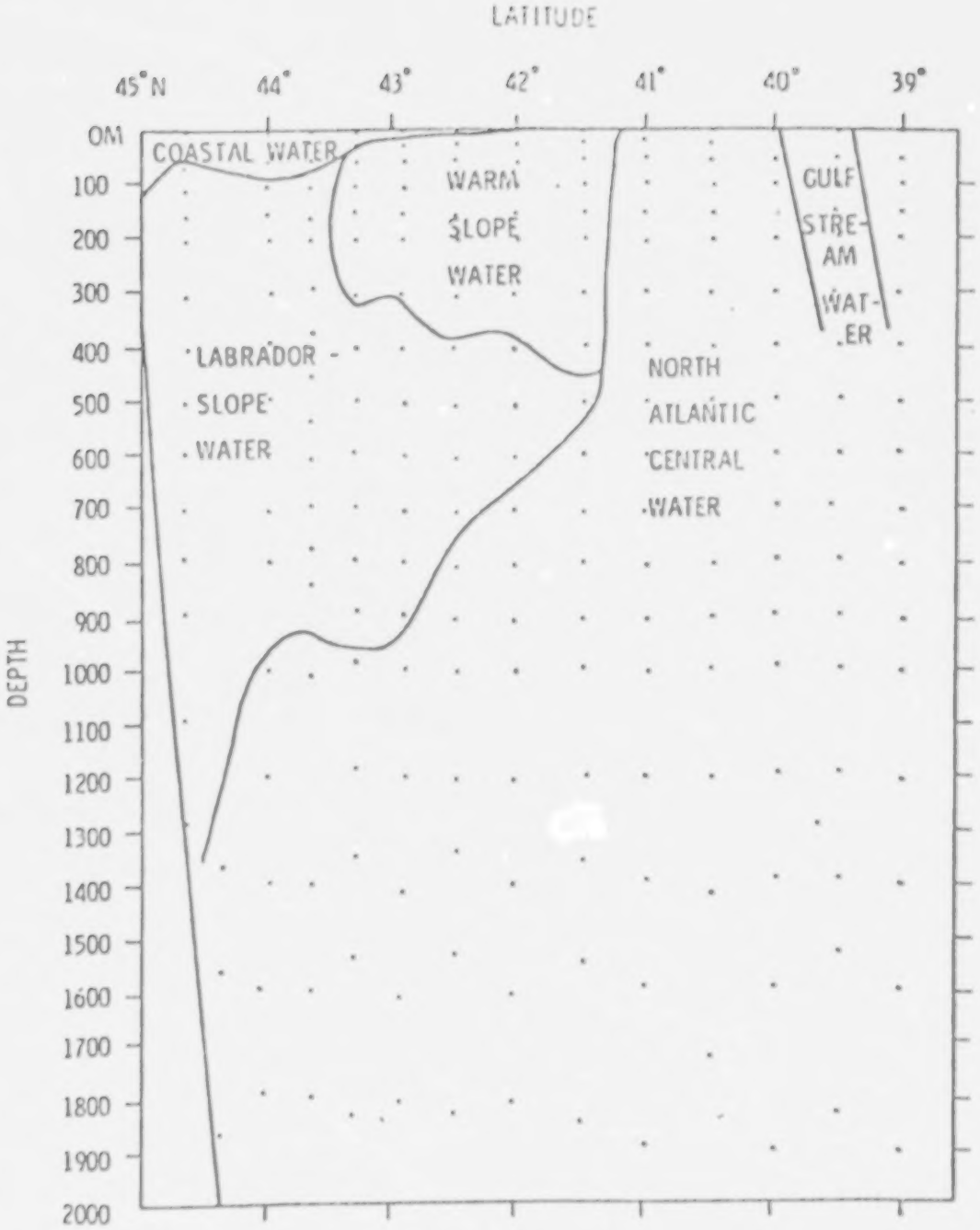


Fig. 24. Approximate positions of the two slope water zones from Section viii - Gulf Stream '60 (from Gatien 1975).

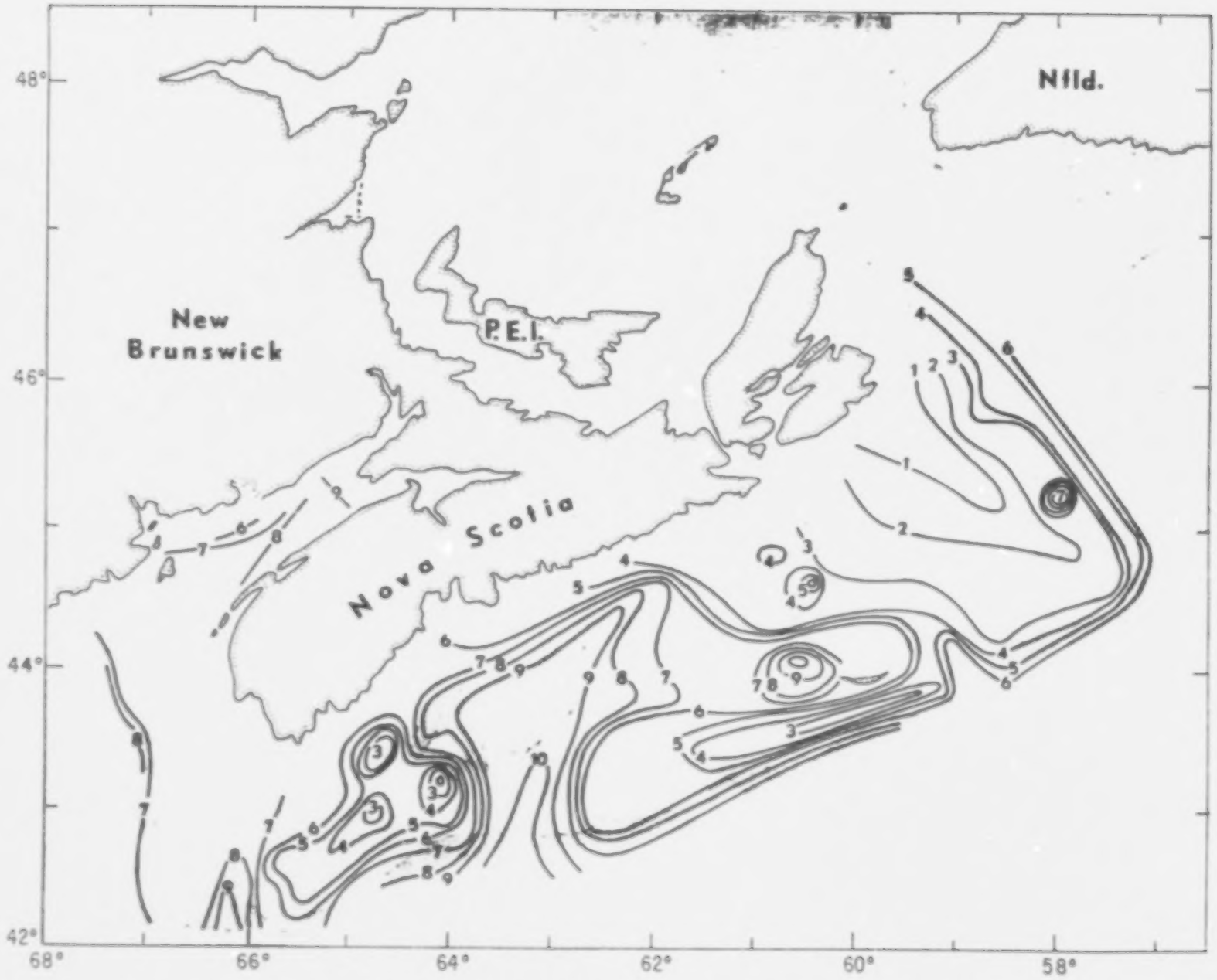


Fig. 25. Bottom temperature (°C) on the Scotian Shelf, June 29 to July 22, 1971 (from Scott 1976).

relatively warm water of apparent slope water origin extends through the Saddle of the Scotian Gulf and across Emerald Basin, typical of these distributions. It is also typical that the relatively warm bottom water is not present over the northeastern portion of the shelf, where the cold intermediate layer extends to the sea floor. Garcia (1981) has used the summertime bottom temperature distributions for the years 1970-74 and 1976-78 to obtain a statistically significant (at the 99% confidence level) relationship between the area of the shelf with bottom temperature above 8°C and the bottom temperature at a site in the Saddle of the Scotian Gulf, for potential use in forecasting the success of any silver hake fishery on the Scotian Shelf.

Further information on the spatial and temporal variability of temperature in the areas of interest is provided by the summary by Drinkwater and Trites (1987) of bottle data from the Scotian Shelf by month and subarea. Figure 26 shows the monthly means, standard deviations, and numbers of observations for temperature at selected depths: at 150 m below the surface in subareas referred to by Drinkwater and Trites (1987) as Emerald Basin, Central Slope, and North Slope, at 100 m depth in the Saddle of the Scotian Gulf, and at 75 m below the surface over western Sable Bank and Emerald Bank (see Fig. 27 for locations). (In most months, the 150-m level is the depth of maximum temperature outside the surface layer in the Emerald Basin and Central and North Slopes subareas. The 75-m level and the 100-m level are the maximum standard depths in the western Sable and Emerald Bank subareas and the Saddle subarea, respectively.) The most striking features of these data are the large range of variation about the means for most months and the apparent lack of strong seasonal cycles. From the point of view of the silver hake migration, it is noteworthy that the summertime temperatures in the lower water column over western Sable and Emerald Banks remain lower than the temperatures at the overwintering depths in Emerald Basin and on the Central and North Slopes, and there is little significant summertime warming of the bottom waters on western Sable and Emerald Banks. There is some suggestion of warmer water in the Saddle in the summer months than in March, but there are not enough data to reach a firm conclusion on this. Other relevant features of these data are the similarity of the monthly mean temperatures at 150 m in Emerald Basin and Central and North Slopes in most months, and the greater temperature variability over Central and North Slopes than in Emerald Basin.

The hydrographic observations on the outer Scotian Shelf have been complemented by two moored current measurement programs carried out by AOL: moorings at 13 sites (Fig. 20) on the shelf and slope for various periods in 1967-68 (Grant and Reiniger 1970; 1971), and moorings at eight sites (Fig. 20) across the shelf break in the Scotian Gulf area between December 1975 and January 1978 (Smith and Petrie 1982).

The principal 1967-68 measurements in the area and seasons (spring-summer) of interest here were at single stations in Emerald Basin, on Emerald Bank, and on the continental slope in the period May-October 1967. These measurements have been discussed by Warner (1970) and Petrie and Smith (1977). The primary results are:

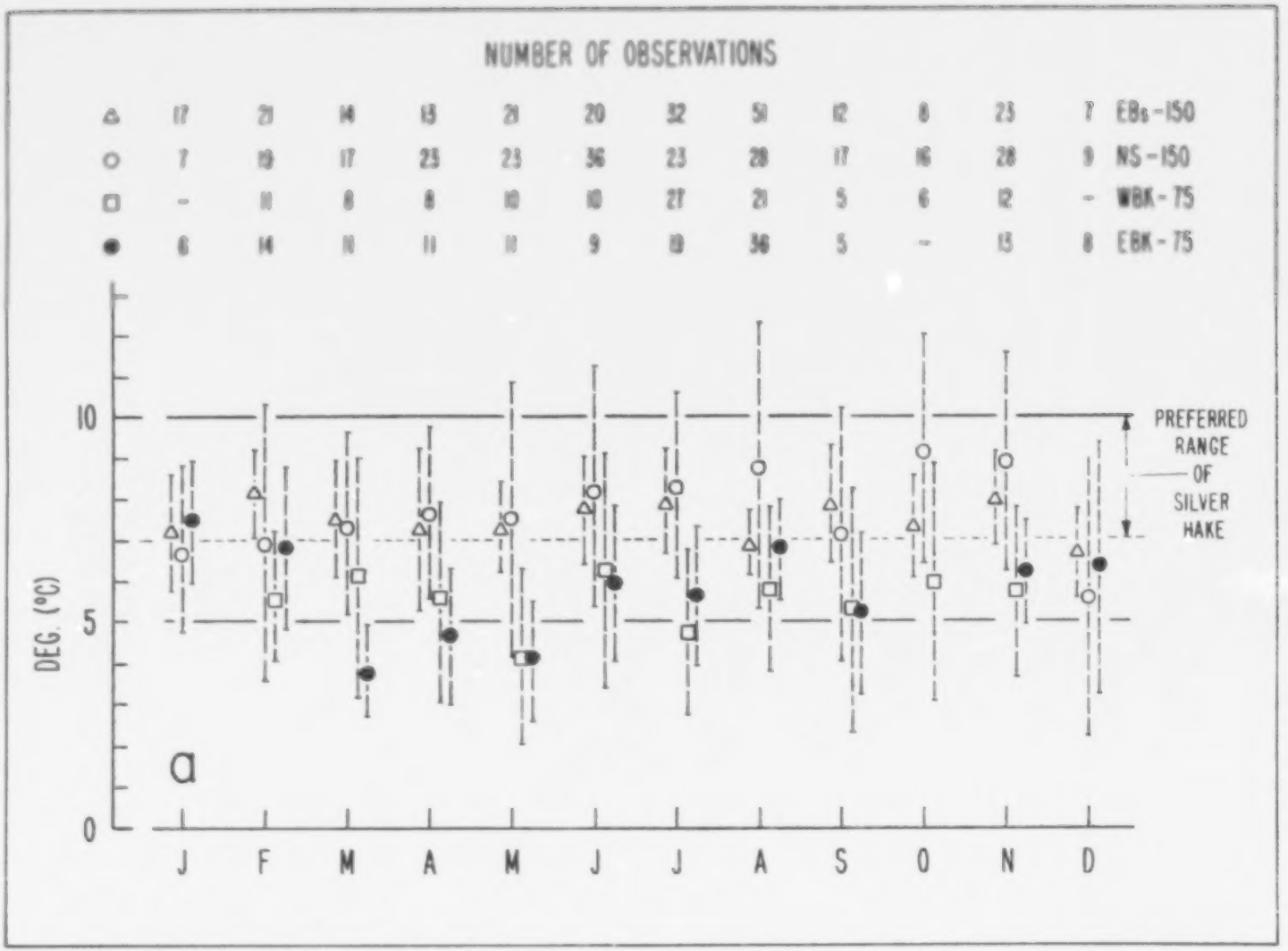


Fig. 26A, B. Number of observations, monthly means, and standard deviations of temperature at selected standard depths in some of Drinkwater's and Trites' 1986 subareas on the Scotian Shelf and slope (see Fig. 27 for location).

Fig. 26A. Emerald Basin, 150 m: EBs-150; north slope, 150 m: NS-150; west Sable Bank, 75 m: WBK-75; Emerald Bank, EBK-75.

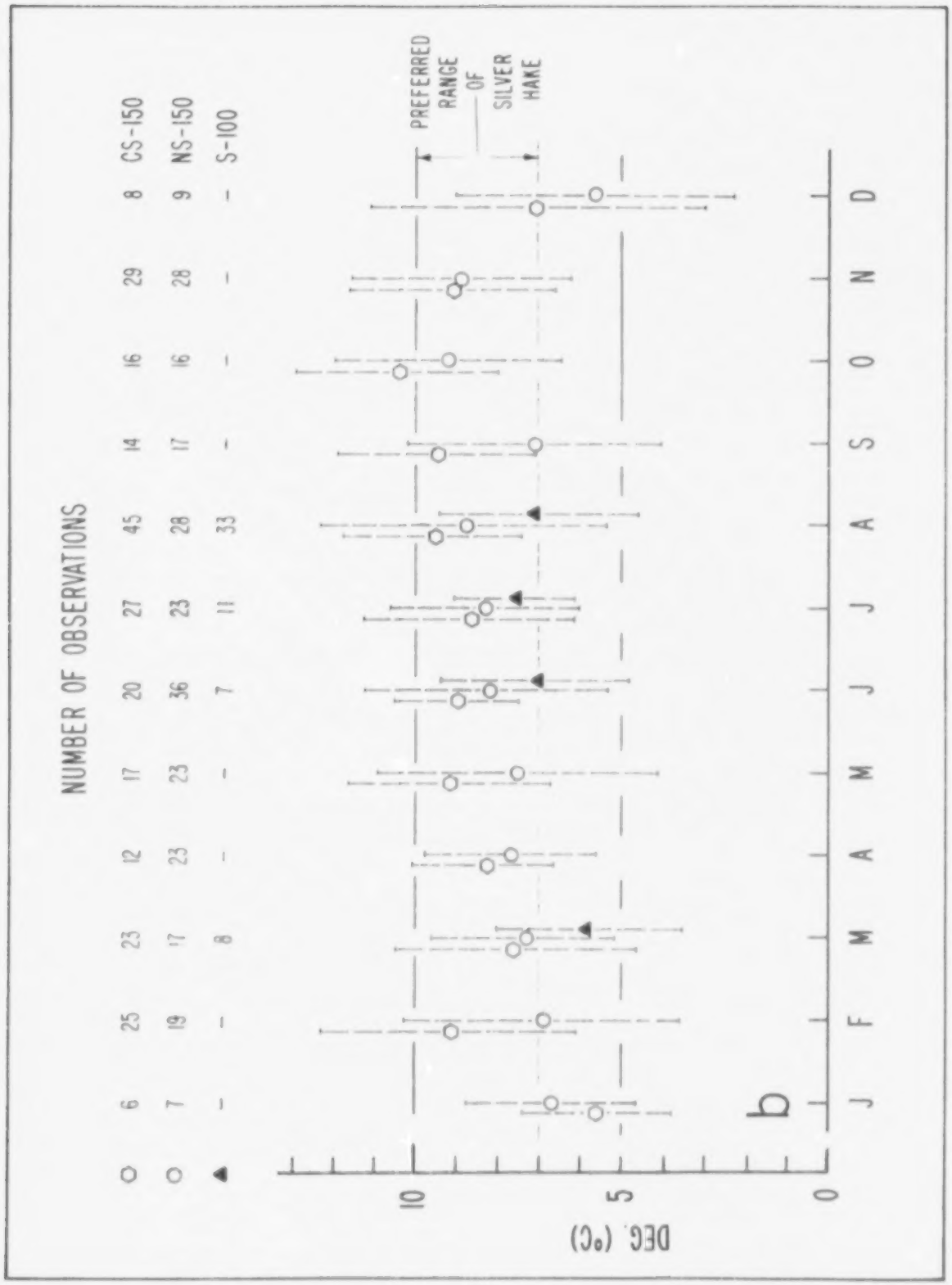
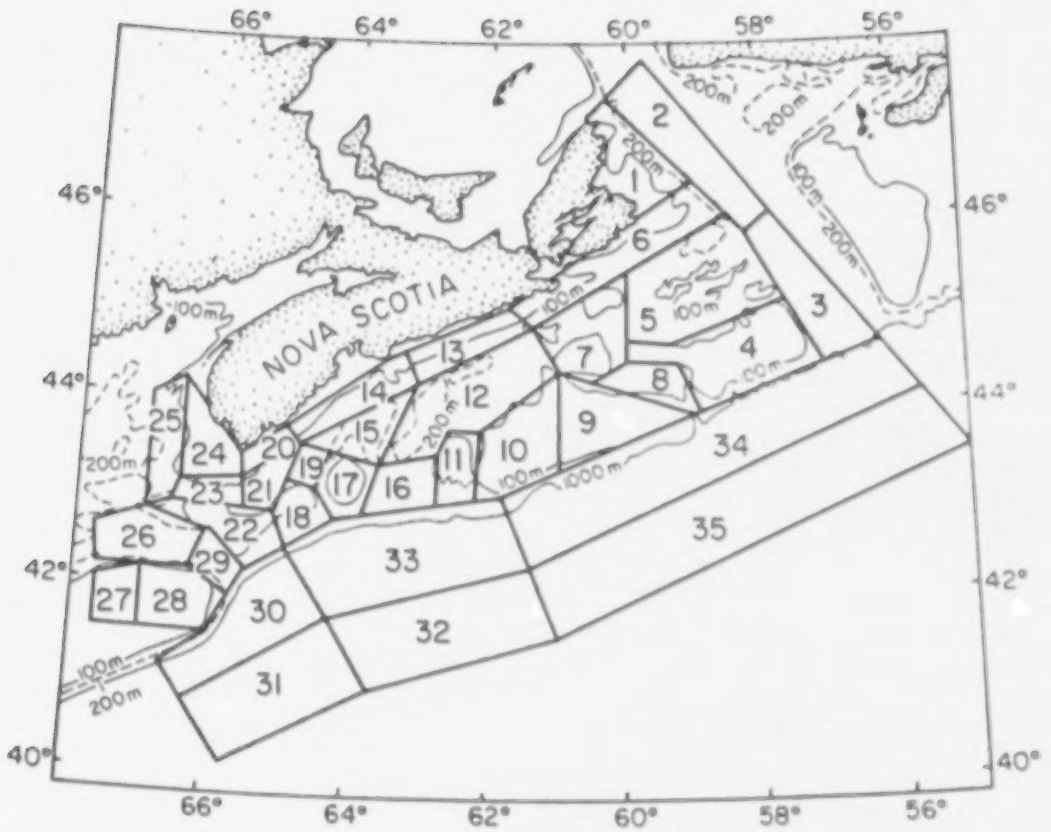


Fig. 268. Central slope, 150 m: CS-150; north slope, 150 m: NS-150; Saddle, 100 m: S-100.



1. SYDNEY BIGHT
2. N. LAURENTIAN CHANNEL
3. S. LAURENTIAN CHANNEL
4. BANQUEREAU
5. MISANE BANK
6. CANSO
7. MIDDLE BANK
8. THE GULLY
9. SABLE ISLAND
10. WESTERN BANK
11. EMERALD BANK
12. EMERALD BASIN
13. EASTERN SHORE
14. SOUTH SHORE
15. LAHAVE BASIN
16. SADDLE
17. LAHAVE BANK
18. BACCARO BANK
19. ROSEWAY BANK
20. SHELBURNE
21. ROSEWAY BASIN
22. BROWNS BANK
23. ROSEWAY CHANNEL
24. LURCHER SHOALS
25. E. GULF OF MAINE
26. GEORGES BASIN
27. GEORGES SHOAL
28. E. GEORGES BANK
29. N.E. CHANNEL
30. SOUTHERN SLOPE
31. SOUTHERN OFFSHORE
32. CENTRAL SLOPE
33. CENTRAL OFFSHORE
34. NORTHERN SLOPE
35. NORTHERN OFFSHORE

Fig. 27. Location of subareas on the Scotian Shelf and slope (from Drinkwater and Trites 1987).

1. The currents on Emerald Bank are dominated by tidal, inertial, and wind-driven (periods of 2.5-7 days) motions with only weak mean flows

2. There are strong lower-frequency (periods greater than ten days) current fluctuations in Emerald Basin and on the slope which do not appear to be associated with wind forcing

These authors also reported an intrusion of slope water onto the shelf and into Emerald Basin in October-December 1968, apparently associated with a mean eastward wind stress and onshore flow measured on Emerald Bank.

The 1975-78 program included current and, in most cases, temperature and salinity measurements for the period December 1975 to January 1978 at a site of 220 m depth on the shelf break near the Scotian Gulf, and for the period July 1976 to January 1978 at sites of 150 m depth in the Saddle of the Scotian Gulf and 220 m depth south of LaHave Bank. Strong subtidal current variability was observed at these sites, with the seasonal mean currents generally being substantially less than the subtidal standard deviations for both the cross-shelf and along-shelf directions (Smith and Petrie 1982). The low-frequency current fluctuations were found to be primarily in two frequency bands: a wind-driven band with periods of two to ten days and in which the current variance was generally correlated with the wind variance, and a lower-frequency band (periods greater than ten days) in which the current variance was correlated with the cross-shore position of the shelf-water/slope-water front (apparently through the occurrence of warm-core rings and associated topographic Rossby waves). The on-shelf fluxes of heat and salt were found to be associated with both the seasonal mean and lower-frequency fluctuating currents, with the mean flow contributions generally greater by a factor of 2-4 and the mean flow heat flux greatest in winter. Strong upwelling from depths of 400 m was found to be associated with along-shelf wind events (Petrie 1983), resulting in the on-shelf flow of relatively cool slope water, particularly in the Scotian Gulf.

This summary indicates that the Scotian Gulf area is one of the more intensively studied parts of the Atlantic Canadian shelf. The picture that emerges is that there is strong spatial and temporal variability in the temperature field, associated with the presence of several water masses in the area and with energetic fluctuating currents resulting from atmospheric and offshore forcing. The existence of a seasonal variation in bottom water temperature, however, as implied by the suggested temperature influence on the timing of the silver hake's on-shelf migration, has not been established.

5.2.3. Some Hypotheses for Further Examination

The fisheries problem outlined in Section 5.2.1 leads to the following hypotheses for physical oceanographic influences on the migration of silver hake onto the shelf.

1. The migration is associated with the on-shelf movement of bottom water of temperature favourable to silver hake (7-10°C).

2. The migration is associated with the warming of the waters over the offshore banks on the outer Scotian Shelf to the favourable temperature range.

3. The migration occurs upon maturation of the hake which occurs earlier when warmer waters are present over the upper continental slope.

The physical oceanographic information summarized above suggests that the following factors might be significant to these hypothesized influences:

- The position of the shelf-water/slope-water front through its influence on on-shelf excursions of slope water

- The magnitude of the along-shelf wind stress through its influence on upwelling and on-shelf excursions of slope water

- The cross-shelf extent of the cold intermediate layer in early summer which may be influenced by the magnitude of the Gulf of St. Lawrence outflow, the severity of the preceding winter on the Scotian Shelf and in the Gulf of St. Lawrence, and the depth of mixing of the summertime surface heat input over the banks on the outer shelf

- The presence of Labrador versus warm slope water over the upper slope

Considering these factors, it is possible to refine the above hypotheses into more process-oriented hypotheses such as the following:

1A. The migration is associated with northward excursions of the shelf-water/slope-water front which result in the on-shelf movement of Labrador and/or warm slope water.

1B. The migration is associated with along-shelf (northeastward) wind stress which results in the (upwelling) movement of Labrador and/or warm slope water onto the shelf.

2A. The migration is inhibited by along-shelf (northeastward) wind stress because it results in the movement of cooler water onto the shelf (Petrie 1983).

2B. The migration is inhibited in years of increased St. Lawrence River outflow due to an increased extent of cool intermediate-layer water on the shelf.

2C. The migration is inhibited following severe winters on the Scotian Shelf and in the Gulf of St. Lawrence due to an increased extent of intermediate-layer water on the shelf.

3A. The migration occurs earlier when Labrador slope water over the upper slope is displaced by warm slope water.

The number of physical factors identified above and the differing hypothesized effects (e.g. 1B and 2A) of their combined influences suggest that the determination and prediction of physical oceanographic influences on

the silver hake migration are not simple problems. For example, the migration may depend not only on the on-shelf movement of slope water, but also on the temperature (i.e. the type) of that slope water.

5.2.4. Current Relevant Research

There is apparently no present or planned physical oceanographic field investigation in the area of interest.

There has recently been a small amount of correlation analysis related to the above hypotheses. Showell and Waldron (1986) used bottom temperature observations taken during Canadian research surveys on the Scotian Shelf and catch per unit effort (CPUE) data for the USSR silver hake fishery south of the SMGL to investigate the hypothesis that there is a reduced availability of silver hake to the fishery when there are warmer bottom temperatures on the shelf. Temperature data from two areas - one with water depths less than 50 fathoms (Area I) and the other with depths between 51 and 100 fathoms (Area II) - were used in linear multiple regression analysis of the spring and summer data for the years 1977-85. The only statistically significant (at the 90% confidence level) correlation (Area I in spring) between the corrected (by dividing by stock biomass) CPUE and temperature (Table 1) was considered to be dominated by one influential year (out of five). Showell and Waldron (1986) also carried out multiple regression analyses of CPUE versus biomass and bottom temperature, and of standardized catch rate versus biomass and July bottom temperature. They found that, with the exception of the one influential year (1982), the bottom temperature did not contribute significantly to the regression and concluded that the data supported the null hypothesis that the catch rates are independent of bottom temperature.

In view of the process-oriented hypotheses outlined above, the availability of wind stress data, and the large standard deviations in the seasonal mean temperatures used by Showell and Waldron (1986), further regression analysis has been carried out by the Working Group using the spring (April-May) and summer (July-August) mean values of the along-shelf (60°C) component of Sable Island wind stress (Table 2). To examine the hypotheses (1B and 2A) that the availability of silver hake south of the SMGL is related to wind-driven upwelling at the shelf-break, the corrected CPUE data were regressed against the wind stress. No significant correlation was found. Furthermore, to examine the hypothesis that the variability in bottom temperature on the shelf is related to wind-driven upwelling, Showell's and Waldron's (1986) temperature data were regressed against the wind stress. The only significant correlation was a negative correlation (at the 99% level) between the bottom temperature in Area II and the wind stress in spring (Table 2). This suggests that wind-driven upwelling results in a reduction in the bottom water temperature on the shelf, as described by Petrie (1983) and assumed in Hypothesis 2A, rather than an increase in temperature as implied by Hypothesis 1B.

Regression analysis was also carried out between a longer time series (1970-85) of standardized CPUE data (Fanning, 1986) and along-shelf wind stress, but no significant correlations were found.

Table 1. Summary of regression analysis between USSR-corrected CPUE and Scotian Shelf bottom temperature, 1977-85 (M.A. Showell and D.E. Waldron, pers. comm., 1986, with modifications). Area I has depths less than 50 fathoms, and Area II has depths in the 51-100 fathom range. n is the number of observations, r is the correlation coefficient, and the confidence level is from the student's t-test based on a normal distribution.

Area	Season	n	r	Confidence level (if greater than 0.5)
I	Spring	5	0.84	0.90
I	Summer	9	-0.34	0.60
II	Spring	8	0.09	-
II	Summer	9	-0.58	0.89

Table 2. Summary of regression analysis between either USSR-corrected CPUE, 1977-85, or Scotian Shelf bottom temperatures, and along-shelf wind stress at Sable Island.

Area	Season	Dependent variable	n	r	Confidence level (if greater than 0.5)
-	Spring	Corrected CPUE	9	-0.16	-
-	Summer	Corrected CPUE	9	0.09	-
I	Spring	Temperature	5	-0.43	0.50
I	Summer	Temperature	9	+0.07	-
II	Spring	Temperature	8	-0.84	0.99
II	Summer	Temperature	9	0.06	-

A joint USSR-Canada investigation of the distribution and feeding of silver hake on the Scotian Shelf is presently being considered for 1988 (D.E. Waldron, pers. comm., 1987). The investigation will involve net tows and bottle observations (temperature, salinity) at standard depths on a repeated grid during the period May-September and will be carried out from a USSR vessel.

5.2.5. Comments and Recommendations

1. Several hypotheses exist for the influence of temperature variability on the timing of the silver hake migration onto the Scotian Shelf. However, these hypotheses are in general not well documented, a leading hypothesis has not been identified, and the plausibility of the hypotheses has not been critically examined considering existing physical oceanographic observations from the outer Scotian Shelf and slope. In particular, the hypotheses assume a seasonal variation in bottom water temperature which has not been shown to exist, nor is apparent.

2. The correlation analyses carried out to date have not revealed a statistically significant relation between the silver hake catch south of the SMGL and shelf bottom temperatures. It is not clear, however, that the temperature observations used are appropriate to the hypothesized influence on timing of the hake's migration.

3. There is a considerable quantity of moored physical oceanographic observations from the outer Scotian Shelf which is of relevance to the silver hake problem. Most of these observations have been described, analyzed, and interpreted in a number of theses and primary publications. The spatial and temporal variability of the temperature field during the 1975-78 AOL measurement program has not been described to the extent required by this fisheries problem.

4. The moored observations indicate that the hydrography and current structure in the areas of silver hake overwintering and migration are complex and variable. The observations have revealed that the dominant subtidal variability in the lower water column is associated with wind events (periods of about a week) and offshore variability (periods of weeks to months), rather than the seasonal heating cycle. This raises the possibility that the hake's migration may be associated with wind- and eddy-induced events, rather than seasonal changes.

5. The spatial extent and seasonal variability of the water with temperature favourable to silver hake have not been determined using the historical data base.

6. The most extensive summary of the seasonal variability in the distribution of temperature on the Scotian Shelf - that of Drinkwater and Trites (1987) - is based on bottle data only, thus using only a fraction of the existing data.

7. It is recommended that,

   i. The spatial extent and seasonal variability of bottom water on the Scotian Shelf and slope with temperature in the range favourable to silver hake be determined using the entire MEDS data base.

   ii. The moored temperature measurements made during the 1975-78 AOL program be examined for evidence of seasonal variability in the Scotian Gulf, Emerald Basin, and shelf-break areas.

   iii. Available data on silver hake distributions and migration be examined in relation to the physical oceanographic observations and descriptions for the years (1967-68, 1976-77) in which the AOL measurement programs were carried out.

   iv. A leading hypothesis for a temperature influence on the timing of migration be identified prior to any field investigation.

   v. Any field program directed toward examining a temperature influence on the timing of silver hake migration be designed in conjunction with physical oceanographers familiar with existing observations from the area. Consideration should be given to obtaining complementary temperature and salinity observations during silver hake abundance surveys with moored measurements of temperature, salinity, and currents at some key sites during the spring and summer. In particular, sites at which measurements have been made previously and interpreted, and which are relevant to the hypothesized migration routes, should be considered. The leading candidates for such measurements appear to be Sites S6 and S1 (1975-78 program) in the Scotian Gulf and Site 3 (1967-68 program) on Emerald Bank. The resulting observations should be analyzed and interpreted in relation to observations of the structure and position of the shelf-water/slope-water front taken from satellite imagery and surface temperature charts, Sable Island wind stress, and the temperature and salinity observations taken during the silver hake surveys.

   vi. Further correlation analyses be carried out involving the existing CPUE data and physical oceanographic indices for: 1) the position of the shelf-water/slope-water front and the number of warm-core rings obtainable from sea-surface temperature charts, 2) the Gulf of St. Lawrence outflow, and 3) the wintertime mixed-layer depth and temperature on the Scotian Shelf and in the Gulf of St. Lawrence. These analyses should be used to investigate the process-oriented hypotheses.

   vii. The relation found by Garcia (1981) between area of warm bottom water and temperature at one site in the Saddle be critically examined using available data.

CHAPTER 6. PHYSICAL OCEANOGRAPHIC SUPPORT IN RELATION TO RECRUITMENT STUDIES

The aim of this chapter is to evaluate the requirements for physical oceanographic research in support of recruitment studies. A dual approach is taken. First, the research questions that were addressed in respectively the Georges Bank herring study and the Flemish Cap cod/redfish study are summarized, then the adequacy of the physical oceanographic support in relation to the stated biological aims is evaluated. In addition, the physical oceanographic component of the Browns Bank haddock study is summarized. It is hoped that a retrospective evaluation of this type will provide insights on future directions. Secondly, in Section 6.2 the recruitment issue is looked at somewhat in isolation from its historical context. What is it that needs to be done in this geographic area (i.e. Atlantic Canada)? Are there particular opportunities for substantive increases in understanding at this particular time period?

6.1. SUMMARY OF PHYSICAL OCEANOGRAPHIC COMPONENTS OF THE GEORGES BANK HERRING, FLEMISH CAP COD/REDFISH, AND BROWNS BANK HADDOCK RECRUITMENT PROJECTS

6.1.1. Recruitment - Georges Bank Herring

There were two components of the ICNAF-sponsored Georges Bank herring program. The first involved annual large-scale surveys for larval herring throughout the Gulf of Maine area during the autumn from 1971 to 1978. The second component involved a more comprehensive study of the oceanography and fisheries biology of Georges Bank itself. The aims of the first component are not clearly stated within the ICNAF documentation, but they have been summarized recently by Grosslein (1986). The large-scale larval herring surveys were designed primarily to identify the geographic locations of spawning within the Gulf of Maine area as a whole, as well as to estimate spawning stock size in the different areas. It was hoped that the distributional data on larvae would complement the other biological studies being undertaken to elucidate the population structure in this geographic area. Five nations (Federal Republic of Germany, France, Poland, USA, and USSR) participated in the surveys. A grid of standard and optional stations covering Nantucket Shoals, Georges Bank, the Gulf of Maine, and the southwestern Nova Scotia area was occupied approximately monthly, with a station spacing on Georges Bank of 15' of latitude and 30' of longitude. At each station plankton samples were collected by bongo and neuston nets and hydrographic data by XBT drops and CTD casts. Nutrients, chlorophyll, and primary productivity measurements were also made in some years. As a consequence, the physical oceanographic observations made during this part of the Georges Bank herring study were limited to the routine collection of temperature profiles and surface salinities at the larval sampling stations, plus salinity profiles on some surveys. Preliminary summaries of the hydrographic data collected in at least some of the years have been presented as ICNAF Research Documents (e.g. Schlitz 1975); an interpretation of the entire data set does not appear to have been produced. The temperature observations, however, have been used in published descriptions of the larval distributions during the survey periods (e.g. Grimm 1983); and the observed dispersion of larvae has been discussed in relation to estimates of Ekman transport (Bumpus 1976; Lough et al. 1979).

The physical oceanographic program in relation to this first component, then, was not substantive. Also, it is perhaps inaccurate to label this survey series as part of a recruitment study. Rather, it provided the setting for the definition of the research questions involved in the second component. In passing, it is worth noting that the distributional surveys accomplished essentially both of their major aims. They provided an independent estimate of spawning stock size of the Georges Bank herring population as it declined dramatically from overfishing. In addition, the spatial distributional observations generated a hypothesis on Atlantic herring population patterns and abundance for the northern Atlantic as a whole (Iles and Sinclair 1982; Sinclair and Iles 1985).

The aims of the second component of the Georges Bank herring recruitment study are very clearly documented in the 1975 ICNAF Redbook (p. 91-92). Of the eight recommendations, three dealt specifically with Georges Bank-Nantucket Shoals herring. They were,

" v) that a concerted effort be made to understand the circulation and diffusive processes above and around the Georges Bank-Nantucket Shoals area;

vi) that a special sampling study to follow an isolated patch of larvae on Georges Bank be attempted in 1975 and/or 1976, in addition to the standard surveys, with a view to identifying the physical processes responsible for larval loss from the system, and providing information on the finer-scale variations in growth, mortality, dispersion, feeding and vertical distribution, as the basis for evaluating the feasibility of quantitative estimation of these processes and sampling errors inherent in the present data base;

vii) that quantitative studies of primary and secondary productivity should be conducted to provide a better basis for relating these phases of organic production to potential fish production."

International research projects under ICNAF were directed toward Recommendations v and vi above, but not Recommendation vii. The extensive physical oceanographic activities in support of the ICNAF Gulf of Maine herring work are summarized below. Although preliminary observations were collected in 1977, the detailed Georges Bank-Nantucket Shoals study did not take place until 1978.

Preliminary physical oceanographic observations on the northern side of Georges Bank were made in the summer and fall of 1977 by American and Canadian scientists. The observations included standard hydrographic stations, drogue tracking, and a dye dispersion experiment. The Canadian observations are summarized by Trites (1978a):

1. 110 CTD stations, including repeated occupation of one north-south section

2. Hourly CTD and Aanderaa current meter profiles during a 25-hour anchor station

3. Visual fluorometer tracking of a patch of rhodamine dye for nine hours

4. Tracking for ten hours of drogues set at the surface 10 m and 30 m

5. Release of 56 drift bottles at the time of the dye release

These observations provided important background information on a strong bottom temperature and salinity front near the historical egg bed sites and on a strong residual current with a large vertical shear along the Bank's northern edge.

The patch study in the fall of 1978 involved eight research vessels committed to activities ranging from broad-scale plankton-hydrography surveys of the entire Gulf of Maine region to detailed, fine-scale mapping of ichthyoplankton distributions and parameters. The initial focus was on an intensive study area on the northern side of Georges Bank (41°45'-42°15'N; 66°30'-67°30'W); but when no herring larvae were found in that area, the focus shifted to Nantucket Shoals where the broad-scale survey had identified a patch of recently hatched larvae. The biological feature of greatest interest in the intensive study area on Georges Bank was a patch of chaetognaths which was mapped six times over a 2-wk period.

The physical oceanographic observations included more than 800 hydrocasts (CTD and bottle stations), 860 XBT drops, 70 Aanderaa current meter profiles, 700 data days of moored current meter measurements, 60 drogue deployments, and a dye diffusion experiment. With the exception of the XBT drops, which were made as part of the broad-scale survey, and of drogue releases in the larval patch on Nantucket Shoals, most of the physical oceanographic observations were taken in the intensive study area on Georges Bank. The moored current measurements were obtained from 27 instruments set between 15 m and 175 m below the surface at six mooring sites on two north-south lines across the Bank's northern edge - three Bedford Institute of Oceanography (BIO) moorings along 67°15'W and three NMFS moorings along 66°40'W. The return rate of good data from the moored current meters was about 60 percent. The Canadian observations in 1978 included about 500 CTD profiles in the Georges Bank area, 34 drogue deployments, two 25-h and one 13-h anchor stations with hourly CTD and Aanderaa current profiles, and a dispersion experiment in which a patch of rhodamine dye was tracked for 20 h.

The physical oceanographic observations made during the patch study provided information on the following features of the physical environment on the northern side of Georges Bank during the fall: the structure and variability of the tidal mixing front along the Bank's edge; the strong tidal currents and the associated tidal excursions; the large internal tide on the Bank's side; the residual currents, including the strong eastward flow along the Bank's edge; the small-scale horizontal dispersion rates; the rates of transfer of passive scalars across the tidal front; and the currents in the chaetognath patch. Preliminary discussions of some of these results were given in Trites 1978b and Wright and Lough 1979, and in the abstracts of the

Second Informal Workshop on the Oceanography of the Gulf of Maine and Adjacent Seas held on May 14-17, 1979. Some analysis results have been included in published descriptions of particular aspects of the physical oceanography of the Georges Bank and Gulf of Maine regions, e.g. of tidal currents (Moody et al. 1984) and of residual currents (Butman et al. 1982). It appears, however, that much of the physical oceanographic observations have not been synthesized and interpreted for primary publication. One exception to this is the study of the internal tide and cross-frontal fluxes by Marsden (1986).

Because of the severe overfishing of the herring population(s) spawning in this area, larval herring were not sufficiently abundant to successfully complete the study. In this sense, the second component of the ICNAF herring program was doomed before it began. The Working Group, however, is interested in evaluating the physical oceanography that was done in support of the program to determine whether it would have been appropriate if herring had been abundant.

When it was obvious that herring larval abundance was too low, the patch study switched to chaetognaths. Some of the physical oceanographic and chaetognath distributional data were recently analysed and presented to NAFO (Lough and Trites 1986). Thus, some evaluation of the usefulness of the physical oceanographic support is possible. The joint collection of detailed distributional data on zooplankton and oceanographic properties permitted a description of persistence of a vertically migrating patch of chaetognaths in relation to circulation and mixing characteristics of Georges Bank. The study in 1978 was a state-of-the-art approach to one of the key issues in fisheries biology. It was not until 1984 that the Danes and Scots in the western North Sea would carry out a study of comparable sophistication. To their credit the full North Sea herring study was reported in the primary literature in 1986. The Georges Bank study, in contrast, remained unanalysed for close to a decade; in fact, the oceanographic data are not yet fully analysed.

In summary, the Working Group concludes that the close collaboration between physical oceanographers and fisheries biologists, in both the planning stages and the research activities, that occurred in the "patch study," is an important ingredient for successful recruitment research. The physical oceanographic input to the ICNAF herring patch study was of considerable significance. Unfortunately, for whatever reason, analysis and publication of results received a low priority. No doubt, part of the reason for the delay was the departure of one of the principal investigators to the west coast, as well as the lower priority for analysis of chaetognaths compared to herring larvae. In addition, it appears that the physical oceanographic component was not designed to address clearly stated physical oceanographic research questions so that its lack of a stand-alone capability may have made the priority of data analysis and interpretation vulnerable to the failure of the larval herring component. The difficulties associated with international collaborative experiments may also have contributed. These problems should not detract from the lessons to be learned from the successful linkages demonstrated between physics and fish that were made possible by joint research by the two disciplines. In retrospect, it appears that significant questions were carefully stated; field studies involving

both disciplines were successfully completed, but the program petered out due to the low abundance of herring larvae and perhaps the lack of a stand-alone capability of the physics program. The study was not brought to completion in a timely fashion.

6.1.2. Recruitment - Flemish Cap Cod and Redfish

As early as 1961, it was recognized that Flemish Cap (fish) populations, because of their circumscribed nature (i.e. surrounded by deep water), provided a unique opportunity for recruitment studies. In the 1961 Redbook, it was stated (p. 72) that,

> "...there is urgent need for more information as regards year-class strengths in these subareas [SA2 and 3]... owing to the complex nature of water movements in these and adjacent subareas, and some uncertainties regarding stock identity, there is need for more up-to-date information concerning spawning, larval success and subsequent drift in relation to contemporary environmental conditions. The probable value of studying these in relation to the isolated fishery of Flemish Cap should be considered..."

And further on in the report (p. 77),

> "The Working Party gave considerable thought to the problem of investigating the distribution of eggs and larvae of the principal commercial species in each Subarea and of plankton studies in general...
>
> They also recognized that the ICNAF Area, however, in which a series of most valuable fisheries are situated on the edge of a major continental slope, may present particularly important and valuable opportunities for a specially co-ordinated attack on the problem. Special reference has been made above to the value of egg and larval studies in Subareas 1 and 2, over the Flemish Cap and on Georges Bank. From north to south, there are a series of spawning grounds which would appear to be particularly vulnerable to deviations in the normal regime of the waters flowing constantly past them and in meteorological conditions...
>
> The Working party therefore strongly recommended that the Commission should plan for a co-operative plankton and hydrographic [oceanographic] survey as soon as possible..."

The preceding long quotations are included both to indicate the interest in Flemish Cap for recruitment studies and also the strong emphasis on the direct role of physical oceanographic processes postulated to generate variability in year-class strengths. The Working Party's report led to the NORTHWESTLANT program. It was not until 1975 that a major recruitment focus was placed on Flemish Cap by ICNAF. The Flemish Cap International Experiment developed from Recommendation 30(i) of the Environmental Working Group of ICNAF which stated (ICNAF Redbook 1975, p. 100) that,

> "...an attempt be made to identify relationships between the various currents around Flemish Cap, the water temperature at appropriate depths and any other relevant environmental factors with the year-class strengths of cod and redfish on the bank, including the role of predation of cod and redfish, and to identify other major gaps which still exist in knowledge of the area as well as research programs needed to fill them;..."

The reasons why this area was considered particularly amenable to study were listed (1975 Redbook, p. 99). These included,

> " i) both the cod and redfish stocks are relatively isolated from the stocks on the adjacent Grand Bank,
>
> ii) the water circulation patterns are likely to be amenable to study,
>
> iii) the area is reasonably restricted in size,
>
> iv) the area is one which, because of its major oceanographic features has been of interest to physical oceanographers for many years, and there exists a useful historical and physical environmental data base. With respect to the latter...no fully co-ordinated and comprehensive analysis has yet been carried out."

The subsequent deliberations and research activities are described in some detail by Lilly (1986). In the intervening time period between 1961 and the mid 1970's, even though the role of advection was still considered important, the role of biological interactions (food limitation and/or predation) in generating year-class variability received increasing emphasis in the research proposals. Nevertheless, the physical oceanographic component was always important in the Flemish Cap study. The field studies ran from 1977 to 1983. The physical oceanographic input to the program is summarized below.

Reviews of the biological and oceanographic conditions on the Flemish Cap (published subsequently by Templeman [1976] and Hayes et al. [1977]) were presented to the Environmental Working Group of ICNAF in 1975, and plans for an international experiment were discussed at a meeting of a Flemish Cap Working Group in Murmansk, USSR, in May 1977 (ICNAF Redbook 1977, p. 83-86). A group of 12 Canadian scientists, including three physical oceanographers from the then Ocean Aquatic Sciences Branch of the Department of Fisheries and Environment, met in September 1977 to plan the Canadian participation in the experiment, resulting in a report to the 1978 annual meeting of ICNAF (Akenhead 1978). Intensified field observations in the Flemish Cap region, particularly by Canada and the USSR, began in 1977 and continued through 1983. In a compendium of Flemish Cap research cruises, Akenhead (1984) has listed 103 cruises to the region during the 1977-83 period. Of these, 88 cruises were identified as having taken temperature and salinity observations.

The physical oceanographic observations taken as part of the experiment largely consisted of:

1. Hydrographic (temperature and salinity) stations occupied by research vessels from the USSR.

2. XBT, Knudsen bottle, and CTD stations occupied by vessels from the NAFC.

3. CTD surveys, moored current meter, and thermistor chain measurements, and satellite-tracked drogue releases made by BIO.

Partial results of the USSR oceanographic investigations have been described in a number of reports and papers to the annual meetings of ICNAF and NAFO (e.g. Kudlo 1979; 1980), and the water circulation patterns derived geostrophically from 26 USSR surveys and one BIO survey between December 1977 and April 1982 have been presented by Kudlo et al. (1984). The distributions of temperature, salinity, and density determined from the NAFC hydrographic data have been presented in two reports (Kendaris 1981a and b), and a substantial fraction of these data (as well as a small fraction of the USSR hydrographic data) have been included in the archives of the Marine Environmental Data Service (MEDS) (Akenhead 1984). A few climatological descriptions of the water mass properties in the Flemish Cap region using the MEDS data base have been published (Akenhead 1981; Keeley 1982; Akenhead 1986a), but it appears that there has not been a detailed analysis or interpretation of the hydrographic data.

The BIO physical oceanographic investigations on the Flemish Cap were primarily carried out on four cruises: in January 1979, in July 1979, in January 1980, and in June-July 1981. In January 1979, four moorings, comprised of ten current meters and two thermistor chains surrounded by surface guard buoys, were deployed on the Cap in an attempt to monitor the physical environment during the spawning and larval growth periods. Two of these moorings were not found in July 1979, and a third was found with the mooring line severed above the lowest current meter so that good data (including temperature and salinity records) were obtained from only three current meters (at two sites). One of the moorings, with three current meters and one thermistor chain, was redeployed in July 1979 but was not recovered in January 1980. In addition, a satellite-communicating thermistor chain, moored on the Cap from April 28 to July 3, 1981, provided good data showing the development of thermal structure in the water column through the larval stage of cod. A preliminary description of the moored current measurements, which reinforced the suggestion of a weak anticyclonic circulation around the Cap, was presented to NAFO in 1980 (Ross 1980), but neither a detailed analysis of the current measurements nor a description of the thermistor chain observations has been published.

The moored current and temperature observations were complemented by the release of six satellite-tracked buoys drogued at 2 to 10 m below the surface and equipped with water temperature sensors. Ross (1981) has provided a preliminary description of the results. The buoys were released in January (2), March (2), and July of 1979 and May of 1980 and remained over the Cap for 50 d on average. Their trajectories suggest a sluggish anticyclonic

surface circulation over the Cap, with exchange with ambient waters occurring in the southeastern corner.

The CTD surveys conducted by BIO consisted of 133 stations in January 1979, 87 stations in July 1979, ten stations in January 1980, and 65 stations in June-July 1981. The results of these surveys have not been published.

The interest of the Working Group is again focused on the adequacy of the physical oceanographic research component for the stated aims of the recruitment study, rather than on the overall success of the program. Given the strong emphasis on the circulation in several of the hypotheses accounting for year-class variability, the physical oceanographic component of the study was perhaps not extensive enough. The loss of moored equipment was a major blow to the physical oceanographic component. It also appears that there was a lack of emphasis on conceptual models and clear strategies for examining specific physical oceanographic hypotheses (leading again to a lack of stand-alone capability), as well as a lack of close coordination between the physical and biological components (probably in part due to limitations on communication with foreign scientists). In the sense that the 1979-80 physical oceanographic component was somewhat exploratory, these problems may have been corrected if the equipment return had permitted further physical oceanographic field work. Nevertheless, what was done has not been adequately analysed and interpreted. Only limited analyses of the hydrographic data collected by NAFC have been published, and the BIO investigations on the Flemish Cap have not been fully analysed and interpreted. Finally, at the recent 1986 Special Scientific Meeting specifically to wrap up the Flemish Cap program, there was no contribution on the relevant physical oceanography.

6.1.3. Recruitment - Browns Bank Haddock

The southwestern Nova Scotia Fishery Ecology Program (FEP), often referred to as the Browns Bank Haddock Program after the area and species of study, is a cooperative program involving the Marine Fish Division (Scotia-Fundy Region), the former Marine Ecology Laboratory (MEL), AOL, and Dalhousie University. The Program was initiated in 1982 and is expected to be concluded with two symposia in 1987 and publication of results in 1988. Its goal was to improve management advice through the study of factors affecting the productivity of an economically important groundfish stock. The haddock stock of the southwestern Scotian Shelf (NAFO Subarea 4X) was chosen for several reasons:

1. There are a number of interacting fisheries for haddock, cod, pollock, herring, scallop, and lobster which enable investigation of multispecies management approaches.

2. The haddock stock is economically very important to the Nova Scotia fishing industry.

3. The history of the haddock stock and its fishery is well defined back to the early 1960's.

4. There are considerable historical data from the area, including ichthyoplankton surveys, primary productivity measurements, and physical oceanographic studies.

The Program consisted of six subprograms and included 31 projects. It involved over 42 research cruises, with a total of some 503 d at sea, mostly during the principal field seasons from 1983-85. Rather than having a single structured program, a "modular" approach was devised, whereby each project was as self-contained as possible so that if one component should fail, the others should be able to continue and produce publishable results. A central steering committee was formed to oversee the entire program, to solicit participation, and to ensure all relevant topics, from physical oceanography to plankton to fish, would be investigated.

The physical oceanography program formed an integral part of the FEP, and was seen as the basis for many of the plankton and distribution studies. The mean and seasonal circulation of this area had been studied previously by Smith (1983), and formed a background to determining the time and space scales for more detailed observations of turbulent dispersion and vertical variation in cross-isobath advection. These mechanisms were thought to strongly influence the aggregation and dispersion of eggs and larvae on the bank, and so became the focal point for interaction with the plankton surveys. Measurements were taken using moored current meter arrays, hydrographic surveys, and drogued drifters. In addition, other environmental data including meteorological measurements, sea level, and frontal analysis of sea-surface temperature were collected.

Considerable effort in the FEP was spent in promoting and maintaining communication between the various subprograms. Quarterly reports were prepared and widely distributed, containing items of interest to participants - abstracts of papers, results of analyses, and schedules of FEP cruises. Annual reviews were also held, involving oral presentations of projects and ongoing reults, for use by other projects. Such regular interaction was greatly facilitated by having all participants belong to a single country, and indeed predominately a single region.

This communication between program components has been the key to ensuring use of the physical oceanographic studies by the various fishery subprograms. In addition, the time scales of analysis were such that the general physical data analysis was always available before analyses of the larval samples and distributional data were completed. This has enabled the distributional data to be readily interpreted in light of the new results from the oceanographic subprogram. It is expected this interaction will be evident from the presentations and publications of the FEP. A recent listing of project proposals indicates that 10% (of a total of 50) have directly involved input from the physical oceanographic component at some stage during the field season or analysis.

The physical oceanographic data, however, could still have been used more fully by the fishery components of the program. For example, the location of stations for the ichthyoplankton and juvenile distributional surveys were set on a regular latitude-longitude grid, without reference to available oceanographic information and the spatial scales described by those

data. It remains to be seen during the final analyses whether this lack of regard at the outset for the physical scales hinders complete interpretation of the distribution of, in particular, the early life-history stages in relation to physical processes. In addition, it is probable that the overall success of the program would have been greater if there had been more fully coordinated interdisciplinary projects (e.g. simultaneous drogue dispersion and egg and larvae distribution studies; formulation and testing of specific models for physical oceanographic influences on the Browns Bank ecosystem), and additional interaction between the physical oceanographers and fisheries scientists. This is reflected by the low percentage of projects in the program which directly received physical oceanographic input.

6.2. OPPORTUNITIES FOR PHYSICAL OCEANOGRAPHIC SUPPORT FOR RECRUITMENT STUDIES

Because of IREP (initiated by the Intergovernmental Oceanographic Commission [IOC] in 1982), there has recently been an increased emphasis by the international oceanographic community on the recruitment problem. In the past it has been a research problem addressed predominantly by fisheries biologists with a minimal amount of descriptive physical oceanography added on. As indicated above in Section 6.1, for two major ICNAF/NAFO programs, the end result of such studies has not been too successful. The Working Group considers that there are real scientific opportunities to be grasped at this particular time in relation to the recruitment problem. The questions, however, have to be considered as oceanographic as much as fisheries biology questions. In general, the fisheries biologists do not have sufficient understanding of the oceanographic processes to adequately design and carry out the studies. Oceanographers need to be intimately involved and have a stake in the success or failure of the program. Future recruitment studies in the northwestern Atlantic could be developed fruitfully within the ICES/IREP initiative.

IREP was adopted by the IOC at the Twelfth Session of the Assembly of that body, in 1982 as Resolution XII-1. The resolution agreed that,

> "...the first major objective of the Commission's OSLR [Ocean Science in Relation to Living Resources] Programme should be to gain a better understanding of the effect of environmental conditions on recruitment of fish stocks, this being one of the central and long-standing but still largely unresolved problems in marine science in relation to living resources."

and also that,

> "...a promising approach would therefore be to develop an international programme comprising a network of investigations into the relevant aspects of the quantitative ecology of selected fish species, coordinated in space and time and using similar techniques (hereafter called the International Recruitment Project, IREP)."

Subsequently, ICES was requested to contribute to IREP. The initial response was the formation of the IREP Study Group which met in Copenhagen in April

1985. The report (ICES C.M.1985/Gen:4) dealt extensively with the broad question of recruitment to fish populations in the northern Atlantic as well as the potential role of ICES in relation to IREP. The Study Group was followed by the formation of a Steering Group on IREP,

> "...to develop a research strategy and prepare proposals and plans for international cooperative interdisciplinary work, promoted and coordinated by ICES on recruitment problems in the North Atlantic area."

The research activities generated should constitute,

> "...a North Atlantic component of the IREP element of the IOC/FAO Programme of Ocean Science in Relation to Living Resources (OSLR), which ICES has been invited to handle."

The IREP initiative, then, is at root oceanographic; the responsibility for the northern Atlantic component is being delegated to ICES. Hopefully this will not detract from the level of commitment of the oceanographic community to the research question (ICES is at present predominantly an organization with fisheries and pollution interests). The Working Group considers the IREP initiative, in that it defines recruitment variability as an oceanographic problem, as timely. In addition, the several themes that have been developed within the IREP provide opportunities to address Atlantic Canada fisheries recruitment problems.

A major theme of the IREP is that comparative studies of different populations of the same or similar species, over relatively short time periods, may lead to substantive increases in understanding the processes involved in generating recruitment variability. Part of the ICES strategy is to identify and encourage the implementation of such comparative studies within the northern Atlantic. Our Working Group has identified two research areas that would benefit from a comparative approach, both involving a significant physical oceanographic component. These involve comparative studies of: 1) cod recruitment in coastal current systems, and 2) scallop recruitment to diverse fished aggregations.

One important constraint hindering progress in studies of recruitment variability is the lack of understanding of the processes involved in generating interannual variability in the circulation and mixing within the egg and larval distributional areas of diverse commercial species of interest. A comparative approach between populations of the same species may be profitable. Cod populations in relation to coastal currents provide one such opportunity. A number of commercially important cod populations are associated with coastal currents which have received increased study by physical oceanographers during the past several years (the Norwegian Coastal Current, the Icelandic Current, and the Labrador Current). In each case, there is a substantive amount of work being done on both the cod biology (including estimates of year-class variability) and aspects of the circulation. Also, Sutcliffe et al. (1983) have inferred that freshwater runoff variability from Hudson Bay, and its influence in the Labrador Current productivity, are important in generating year-class variability in northern cod. The Working Group feels that Canada could profitably take the lead in

initiating a comparative analysis on the underlying physical mechanisms controlling interannual variability in the circulation of coastal currents and the role of freshwater runoff in this process. Such an analysis would be complementary to AOL's ongoing study of Labrador Current variability.

It has been empirically observed that the scallop aggregations of commercial concentrations of Placopectin magellanicus are geographically persistent over several decades (Sinclair et al. 1985). The extant hypothesis for the source of recruitment to the diverse scallop aggregations involves supply from contiguous areas due to surface-layer residual circulation. An alternate hypothesis is that the aggregations are to a large degree self-sustaining (i.e. the fished aggregations are populations). The physical oceanographic processes of mixing and circulation within at least parts of the distributional areas of sea scallop are relatively well understood (the species is distributed from the Mid-Atlantic Bight to the Gulf of St. Lawrence). A careful description of the relatively fixed patterns in the distributions of scallop aggregations in relation to residual circulation patterns should lead to specific tests of the relative importance of drift versus retention of larvae in providing the source of recruitment to different aggregations (populations?). In the Gulf of Maine area where the tidal circulation is dominant and well understood a combined modelling and observational program may be possible. Again, the Working Group feels that a comparative study on recruitment to different scallop aggregations in relation to circulation and mixing features would be fruitful and consistent with one theme of the IREP initiative.

A third example (but one not involving a comparison of populations) where there is an obvious opportunity to increase understanding in recruitment involves the Magdalen Islands lobster fishery. Sutcliffe (1972; 1973), using a correlation approach, noted a positive statistical relationship between freshwater runoff in the St. Lawrence drainage basin (i.e. the RIVSUM signal) and lobster landings several years later. The relationship has proven to be predictive during the interim period (Sinclair et al. 1986a; Drinkwater 1987). The causal mechanisms, however, are not understood and have not been investigated in a field study. Bugden et al. (1982) reviewed the overall question of freshwater runoff effects in the Gulf of St. Lawrence in considerable detail. The Working Group feels that the first step is to evaluate the manner in which the physical oceanography of the Magdalen Shallows (in particular around the Islands in question) varies as a function of changes in runoff (circulation, mixing, stratification, etc.). Subsequent to a better understanding of the physics, hypotheses concerning recruitment itself could be better defined. Given the predictive power of the "Sutcliffe relationship," the Department should mount a substantive recruitment program in this geographic area. Studies of the physical oceanographic processes in relation to runoff are a critical component. This is an obvious and major area of interest for the Maurice Lamontagne Institute.

In summary, the Working Group was encouraged by the IREP initiative of the IOC in that it defines the recruitment problem as an important high-profile oceanographic question. The experiences derived from previous major recruitment projects in the northwestern Atlantic infer that dynamical physical oceanographic studies need to be an integral component of

recruitment projects, in particular those involving egg and larval stages. Three potential cases for recruitment research involving physical oceanography are identified (cod, sea scallops, and Magdalen Islands lobster). Each case, however, requires a detailed analysis to investigate the tractability of the physical oceanographic component.

6.3. COMMENTS AND RECOMMENDATIONS

It is noted that two of the major recruitment studies undertaken in Atlantic Canada have not been brought to completion in a timely fashion, and have not generated many publications in the primary literature. Also, linkages with the physical oceanographic studies have been less than optimal. Research management does not appear to have pushed these studies ahead when it was apparent that they were floundering. It is recommended that,

1. Any major Departmental initiative involving recruitment be conceived and planned as an oceanographic program as much as a fisheries biology program. The physical oceanographic components of the program should be given a high priority, and the scientists involved should have a stake in its success or failure.

2. Canada take the lead in initiating a comparative study of the interannual variability in the circulation of coastal currents having cod populations (Labrador, Iceland, and Norwegian coastal currents). The study could be a contribution to IREP.

3. A comparative recruitment study be carried out on sea scallops. The primary aim of the study would be to evaluate the horizontal scale of dispersion of scallop larvae from different commercially important aggregations (populations)? The study could contribute to an understanding of the source of recruitment rather than the annual variability.

4. A recruitment study on Magdalen Islands lobsters be carried out. Initially, it is necessary to evaluate the influence of freshwater runoff from the St. Lawrence drainage system on downstream circulation and mixing around the Magdalen Islands. The initial physical oceanographic study is required prior to the definition of hypotheses underlying the statistical relationship between river runoff and lobster landings in the Magdalen Islands.

CHAPTER 7. PHYSICAL OCEANOGRAPHIC SUPPORT IN RELATION TO LONG-TERM CHANGES IN ABUNDANCE LEVELS OF COMMERCIALLY EXPLOITED POPULATIONS

7.1. TWO POINTS OF VIEW ON MONITORING

There were substantive differences of opinion within the Working Group on the appropriate approach for monitoring of physical oceanographic properties in relation to long-term changes in abundance of commercially exploitable populations. At one extreme it is considered important to be able to describe the environment on an interannual time scale without

necessary reference to a particular fisheries problem. This has been the approach taken by the fisheries laboratories since the turn of the century, usually in the form of standard hydrographic lines run across the continental shelf or measurements made at fixed stations.

The Newfoundland hydrographic monitoring system established in the early 1950's is a representative example of the underlying philosophy. In setting up their oceanographic monitoring system the fundamental hypothesis was that the oceanographic climate of the Labrador Shelf to Grand Banks area, from the point of view of fisheries, was dominated by the Labrador Current and the warmer slope water beneath it in which most commercial species of fish were believed to overwinter. Thus, several hydrographic sections were established (some based on USA Coast Guard sections) across the Labrador Current and on the southwestern edge of the Grand Banks where it was hoped that incursions of slope water over the Banks could be monitored. It was also hypothesized that provided these sections were occupied at the same time every year, seasonal variability would be minimized and thus the sections would provide an index of interannual variability against which fisheries events could be examined. Further, to allow for an examination of seasonal effects and also to allow corrections to be made for time variations in seasonal effects, a near-shore station (Station 27) was also established where the intention was to occupy it at least twice monthly. Based on this rationale the monitoring system was set up. Unlike most of the biological monitoring programs which have changed dramatically through the years, changes have been few and far between in Newfoundland's oceanographic monitoring program. Some of the sections were eliminated (southwestern Grand Banks section) where high-frequency variability was clearly compromising any clear annual indices, and greater emphasis was placed on the Flemish Cap section. On the whole, however, few changes have been made and the oceanographic monitoring program receives a high priority within the fisheries laboratory.

In summary, at this extreme, it has been considered that a long-term description in itself, without specific reference to a particular fisheries problem, was the appropriate strategy for the past several decades. If one had waited until the fishery problems were sufficiently well understood to design specific monitoring programs, there would not now be a 30-yr time series for the respective sections and Station 27. The major criticism of this point of view is that such monitoring should not proceed for 30 yr (nor even 10 yr) without a rigorous quantitative analysis of the extent to which monitored variables are representative of the physical oceanographic features of interest, whether that interest be fisheries or purely physical oceanographic. It appears that such an analysis has not been carried out for either the Newfoundland section's monitoring program or the AOL Labrador Current monitoring program. The other reservation regarding this point of view is that, given the severely limited resources available for physical oceanographic measurements in the Atlantic zone, priority should be given to more process-oriented observational studies which are designed to examine either specific physical oceanographic hypotheses or hypotheses for oceanograhic fisheries interactions. In spite of these reservations regarding the particular monitoring strategy, there is unanymity in the Working Group that the commitment of the Newfoundland laboratory to oceanographic monitoring is an example of the degree of commitment required

to obtain the physical oceanographic information appropriate to the fourth category of fisheries research questions.

At the other extreme, it is argued that monitoring should not be defined without reference to a specific fisheries problem. Identification of the fishery problems and their appropriate physical oceanographic requirements were viewed as integral steps in establishing appropriate monitoring strategies. A three-step approach was considered appropriate from this perspective. First, available oceanographic data should be used to formulate initial hypotheses involving fisheries/physical oceanographic interactions. Secondly, process-oriented field studies of the type outlined for northern cod and silver hake (Chapter 5) should be carried out. Such studies in principle should identify causal relationships between oceanographic variables and fisheries-related responses of interest. The identification of the pertinent variables, and their temporal and spatial scales, then allows the third step - development of an oceanographic monitoring program with tested and clearly defined linkages to the specific fishery problem of interest.

Proponents of this point of view on monitoring stress that, once the relevant variables for monitoring have been identified, the time and space scales should be determined in relation to both the fishery problem and physical oceanographic processes. For example, if recruitment is under study, the temporal scale for monitoring may range from 1 d to 2 yr, depending on whether a specific critical period or the whole of the early life history is being examined. Similarly, the spatial scale could range from 10^1 to 10^6 m, representing small-scale turbulent to large-scale transport and retention processes. If the distribution and migration of adults is the problem under study, the temporal scale may range from months for migration studies (e.g. northern cod and Scotian Shelf silver hake) to years for interannual changes in distribution resulting from changes in ocean climate. Spatial scales would represent the bounds of the adult population, representing perhaps the scale of a typical bank (tens of kilometers) for groundfish or shellfish, or the scale of the continental shelf (hundreds of kilometers) for more widely ranging pelagic species.

In designing the physical oceanographic monitoring component of such studies, careful consideration must also be given to the inherent variability in continental shelf environments of most physical variables over a wide range of temporal and spatial scales. It must be clear that variability at scales smaller than those being measured has not been aliased into apparent variability at longer time and space scales.

A further complication in determining from the fishery problem the appropriate scales for monitoring the physical variables is the potential cascade of variability from shorter to longer scales; e.g. a few short storms during a period of peak spawning may disrupt a year's recruitment (Bakun 1984). This implies it may not be sufficient to monitor variables on the same scales as defined by the fishery problem, but perhaps it should entail shorter scales.

It was noted that at present there are no oceanographic monitoring programs that have been defined by this three-step process. Further, present

understanding of the population biology of marine populations in relation to oceanographic variables is not sufficiently well developed to define a "problem-specific" monitoring program.

In the next sections (Sections 7.2 and 7.3), existing oceanographic monitoring programs in Atlantic Canada are summarized and their usefulness in fisheries research evaluated.

7.2. EXISTING LONG-TERM MONITORING PROGRAMS

There are several long-term programs in the northwestern Atlantic which measure the seasonal and interannual variability of a number of physical oceanographic properties. These include sea level, coastal sea-surface temperature, the hydrographic sections program, and variability of transport by the Labrador Current. Some of these programs were established independently of specific fisheries problems, and as such are consistent with the first point of view on the appropriate approach to monitoring. The output from these studies should be seasonal and interannual descriptions of the physical oceanographic variables, which would then be available to fisheries scientists for use in the fourth category of fisheries research problems (Chapter 3). Any of these programs, however, could also become directly related to a specific fisheries problem if a detailed process study established they are monitoring key variables on the appropriate scales.

In this section the existing long-term monitoring programs are reviewed briefly to establish whether they are able to provide descriptions of interannual variability, while in the next section the use of these monitoring data by fisheries research programs is reviewed.

7.2.1. Oceanographic Sections Program

Hydrographic conditions of shelf waters have been monitored for several decades along a number of sections by several countries in the northwestern Atlantic. In 1976 ICNAF standardized the sections and station locations, and recommended that oceanographic monitoring by all countries be conducted at these sites (ICNAF 1978 Sel. Papers No. 3:109-115) (Fig. 28).

Canada has monitored standard oceanographic variables along the Seal Island, Bonavista, Flemish Cap, and Halifax sections since 1950, one to four times per year. Regular monitoring of the Halifax section ceased after 1977 when it was determined that the sampling design was inappropriate to detect interannual variations. As this is one of the few such monitoring programs conducted by Canada to be reviewed for its capacity to detect interannual variability with confidence, it will be discussed here in some detail. Prior to 1960, it is noted that the program also included sections in the Bay of Fundy and Gulf of St. Lawrence.

The Halifax section consisted of seven stations oriented normal to the coast from Halifax to the shelf break (Fig. 20 and 28), and was sampled for temperature and salinity at several depths about once per season. With only four surveys per year it was determined that the data were inappropriate to

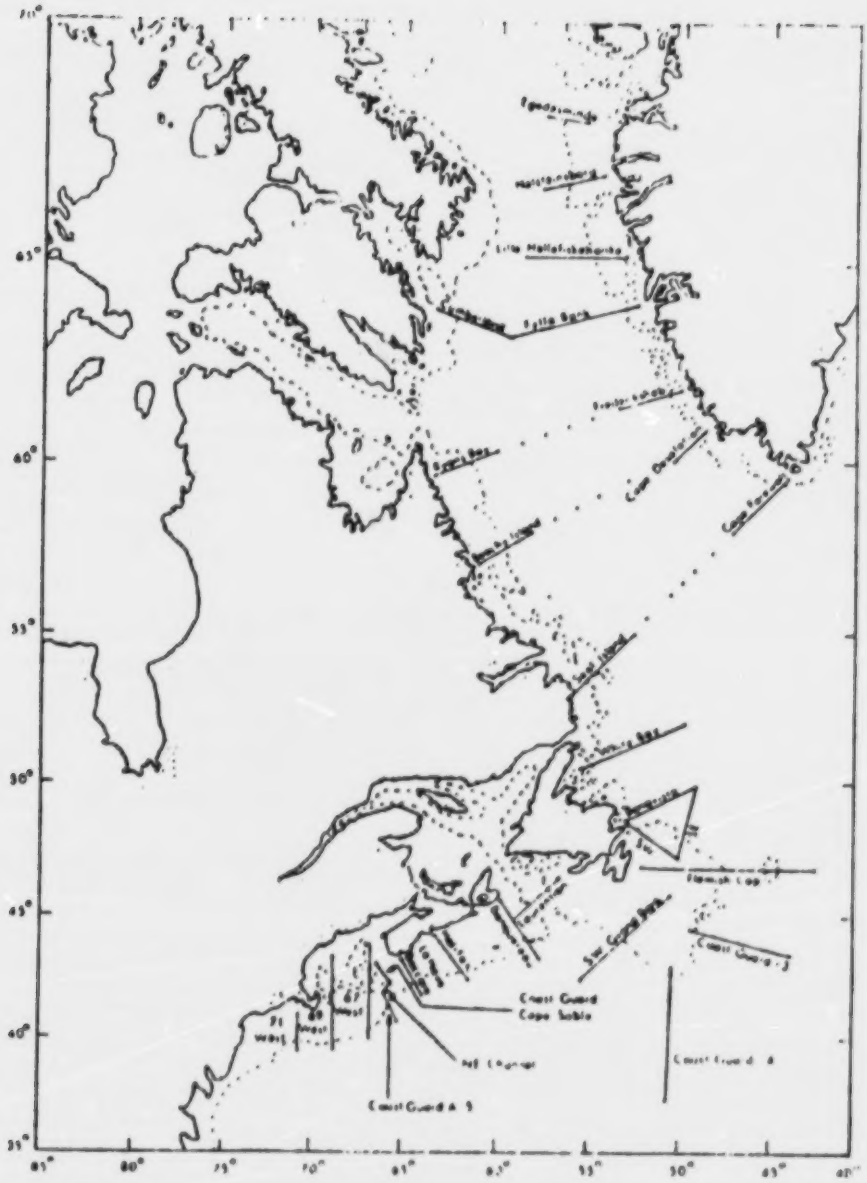


Fig. 28. Standardized ICNAF oceanographic sections for the northwestern Atlantic (from ICNAF 1978, Selected Papers No. 3: 107-115).

detect interannual variability because of severe aliasing (Mann and Needler 1967; Drinkwater et al. 1979), i.e. there was significant variability at frequencies higher than seasonal. Therefore, much of the observed interannual differences in properties along this transect may have resulted from this high-frequency variability. During months when the Halifax section was sampled twice within 1 to 2 wk, there occurred up to 80% of the year-to-year variation in volume transport and up to 90% of the interannual variation in mean temperature (Drinkwater et al. 1979; B. Petrie, pers. comm.).

Some of this high-frequency variability may have resulted from the dynamic nature of the Scotian Shelf and the locations of stations near potential frontal regions. Petrie (pers. comm.) analyzed a detailed 1967 CTD survey that was conducted within 15-mi (N-S) by 22-mi (E-W) boxes around Halifax section Stations 2 and 3 (45 CTD stations in each box); sea-surface temperatures varied from 9.6-19.1°C around Station 2 and from 13.7-20.2°C around Station 3. It was concluded that the Halifax section did indicate seasonal trends for some variables (e.g. Drinkwater et al. 1979) but was inadequate to resolve interannual variability for climate studies, and so was discontinued.

Attempts have been made to use other oceanographic sections along the Canadian Atlantic coast to determine interannual variability, e.g. off Newfoundland and Labrador (Akenhead 1986b) and off West Greenland (Buch 1986). With generally only one occupation of each transect per year, the data may be severely aliased; this point was recognized by Akenhead (1986b). It appears that the data from most of these ICNAF/NAFO sections have not been critically examined by physical oceanographers to determine whether they adequately detect interannual variability. These critical examinations should be made if the sections program is to be of use in describing changing conditions for input to fisheries research activities. If periodic occupations of a section are inadequate, then other techniques (such as moored sensors) should be considered.

One example of a long-term (10 yr) oceanographic monitoring program using moored current and temperature/conductivity sensors is that being conducted by AOL of the Labrador Current. The objective of this program is to study seasonal and interannual variations that may be related to the marine or terrestrial climate (Lazier 1981). The extent to which the measured variables in that program are representative of wider-scale oceanographic conditions in the Labrador Current or on the Labrador Shelf, however, has not been established. Conclusions to date indicate there is a seasonal cycle in the transport of the Labrador Current, driven by freshwater runoff from areas further to the north and west (Lazier and Wright 1985). If a program such as this should prove to be appropriate for detecting interannual changes of ocean climate, particularly of temperature, salinity, and transport, it should be of great use to fisheries studies on the Labrador Shelf and Grand Banks.

7.2.2. Coastal Station Monitoring Program

There have been at least two long-term coastal monitoring programs in Atlantic Canada: the tide gauge network and the coastal temperature program.

The tide gauge network was first used to enable better prediction of tidal elevations, but the data can also be filtered to reveal lower-frequency variability in mean sea level which can be used to indicate contiguous ocean processes. The longest continuous data set in the coastal temperature program is from St. Andrews, N.B., where sea-surface temperatures have been recorded twice daily since 1921. There have been two versions of this program: the first, from the 1920's to the 1970's, involved up to 14 stations with temperatures measured twice daily (Lauzier and Hull 1969), which was succeeded by a program using Ryan recording thermographs. This latter program has gradually reestablished the coverage of the earlier program and in addition processes the data for a number of fisheries studies which collect their own site-specific thermograph data.

Akenhead et al. (1981) have examined the earlier coastal temperature monitoring program for its ability to detect changes in ocean climate (one of the principal objectives of the program). They found that these shore stations recorded the trends in temperatures fairly well, but not necessarily the magnitude of changes or absolute value of temperature at any one place (temperatures could vary considerably between relatively closely spaced stations). Akenhead et al. (1981) felt that for general monitoring of sea-surface temperature, ships of opportunity data should be used to extend spatial coverage; for site-specific studies, moored arrays would be better than occasional visits by vessels. For sea-surface temperature variations for periods of less than 1 yr, a given station was usually representative of a small area (tens of kilometers). Therefore, if interannual variations are to be resolved, temperature measurements should be made at the site of a fishery study, rather than from some possibly distant shore station (Akenhead et al. 1981). On the other hand, the higher-frequency, smaller-scale variability may be partially filtered out by increased spatial averaging of the data.

The recent coastal temperature program has tried to address these recommendations. It has replaced the former twice-daily measurements with continuous recording thermographs and, in addition, has encouraged their use in several site-specific fisheries studies. Petrie (pers. comm.) cautioned that vertical thermal stratification can be a serious problem in interpreting data from most of the deployment sites. With the exception of western Nova Scotia and the Bay of Fundy, most Atlantic coastal waters have extensive vertical stratification for much of the year. It is therefore very important to know the temperature profile at a site so that if interannual or spatial differences occur, they can be interpreted as real and not resulting from different depths or locations of sensors. Deployment of sensors at more than one depth may be a solution to the stratification influence problem. Even if this is so, there does not appear to have been a rigorous quantitative analysis of the spatial and temporal scales of variability in the recent coastal temperature observations and of the extent to which the Ryan thermographs are reliably able to detect interannual variability in coastal and shelf temperatures. It would seem timely that such an analysis take place.

Long-term monitoring programs of the type described here, if they can be shown to indeed be representative as assumed, should be adequate to develop interannual descriptions of at least temperature, salinity, and velocity

(over the Labrador Shelf), for use in studying fisheries problems. Annual descriptions of ocean climate have become available recently through NAFO (e.g. Trites and Drinkwater 1985), but report the data on such large temporal and spatial scales that they may be inappropriate for specific fisheries studies.

7.3. USE OF LONG-TERM MONITORING PROGRAMS IN FISHERIES RESEARCH

The fourth category of fishery research questions (i.e. long-term changes in abundance levels of exploited populations) involves requirements for descriptions of continental shelf waters on interannual time scales. Section 7.2 has described several long-term physical oceanographic monitoring programs in Atlantic Canada and the inherent problem of high-frequency variability. This section examines the use of such data in fisheries research programs.

There have been several studies to examine and develop hypotheses concerning fisheries-environment interactions in Atlantic Canada, some of which used data derived from long-term monitoring programs. These include the Georges Bank, Flemish Cap, and FEP studies previously discussed, as well as several smaller studies, for which a partial listing can be found in Shepherd et al. 1984 and Brodie and Baird 1986. Some of these studies involve short-term experimental programs to test (or develop) explicit hypotheses concerning fisheries-physical oceanographic interactions that were defined on the basis of exploratory analyses of data from oceanographic monitoring programs.

A good example of how such site-specific tests of hypotheses may expand to include data collected by long-term monitoring programs is provided by studies using Ryan thermographs. The initial coastal temperature network had 14 stations scattered throughout the Maritimes, while the present network has fewer. It was noted (Section 7.2) that temperature data should be collected at the site of a fishery project rather than extrapolated from data collected at some possibly distant shore station. This has led to an increase in recent years in the use of Ryan thermographs for fishery studies (Fig. 29) involving both short and long deployments (Table 3). These studies may then be able to extrapolate their results backward in time with reference to the most appropriate shore station of the Coastal Temperature Monitoring Program.

There have been several attempts to relate long-term data series taken from the Coastal Temperature program to recruitment studies of important commercial species in Atlantic Canada. Martin and Kohler (1965) related cod recruitment to coastal temperatures, while Sutcliffe (1973) and Sutcliffe et al. (1977; 1983) examined relationships among annual commercial catches of several species, temperature, and freshwater runoff from the St. Lawrence River or Hudson Bay. The relationships derived continued to be useful in predicting recruitment for certain stocks (Drinkwater 1987), although they are all based on correlations for which several explanatory mechanisms have been proposed, all of which remain untested.

The Working Group was unable to identify any studies in oceanographic monitoring which were built upon site-specific process studies. The

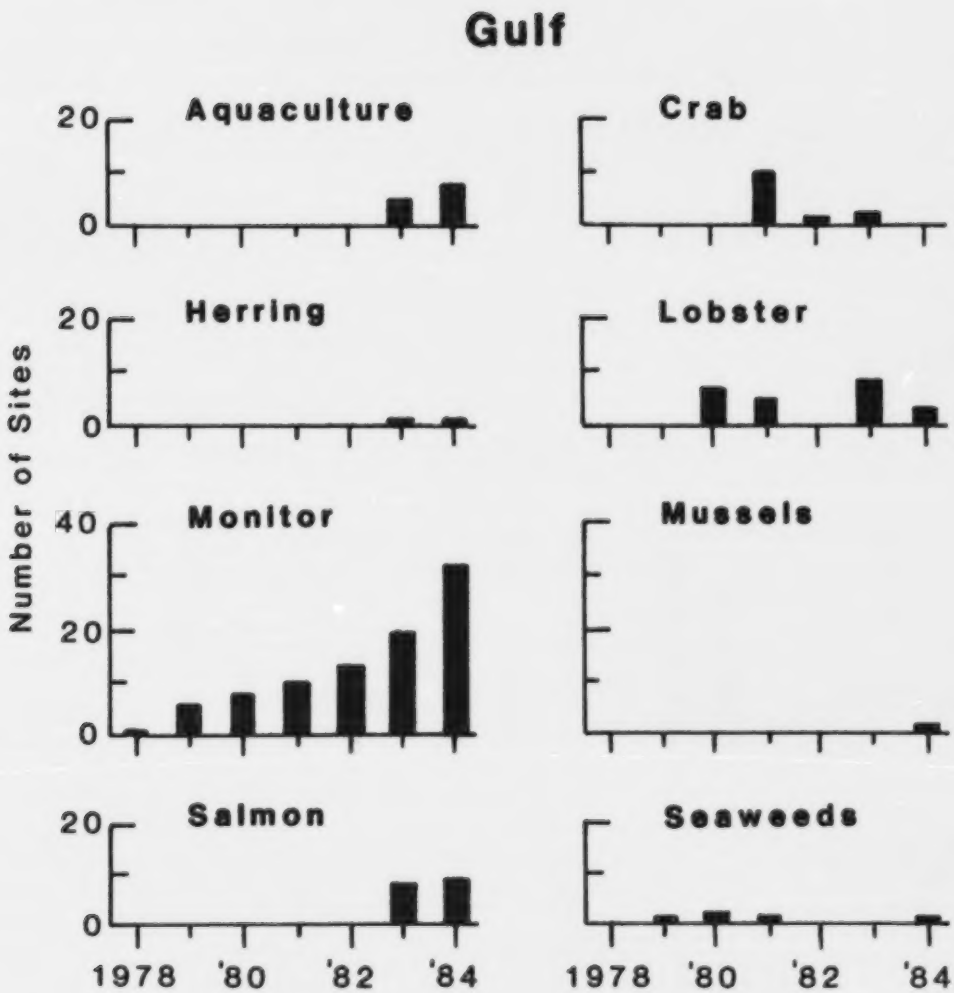


Fig. 29. Use of Ryan thermographs by region and fishery category. Monitor category refers to all uses not identified in any other fishery uses (from Petrie et al. 1986, unpubl. MS).

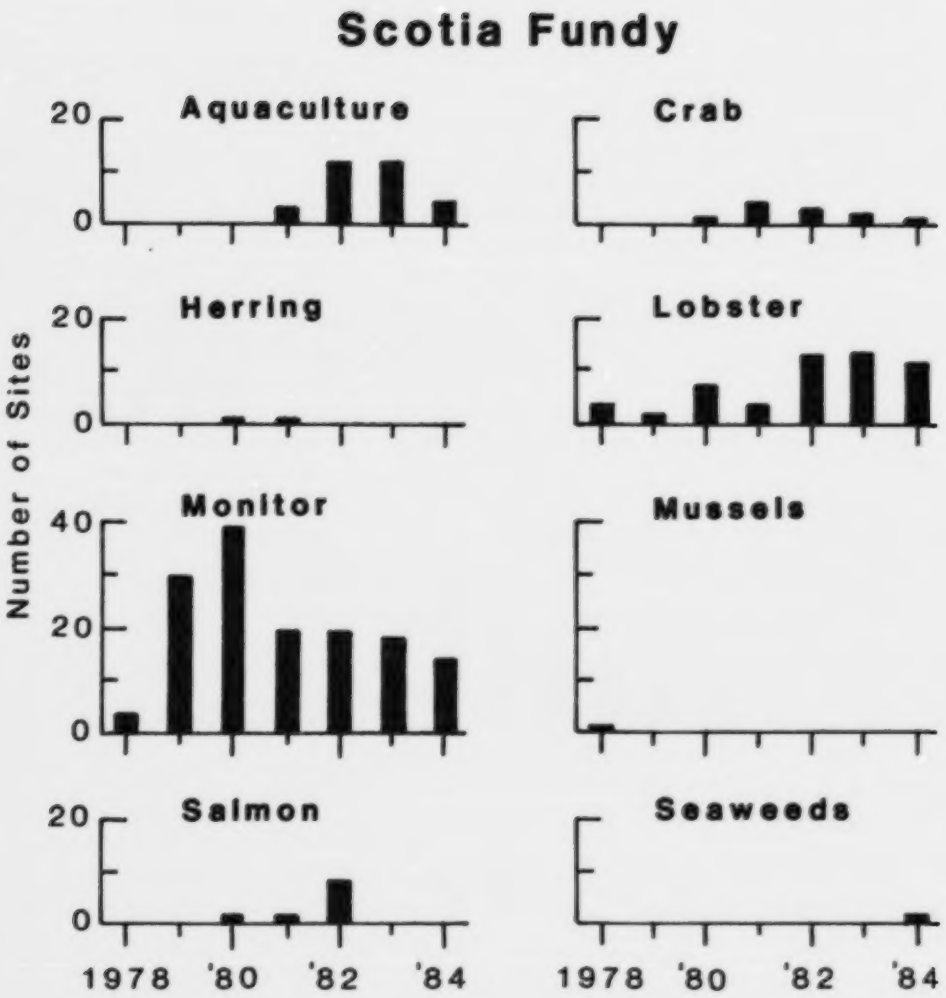


Fig. 29 continued.

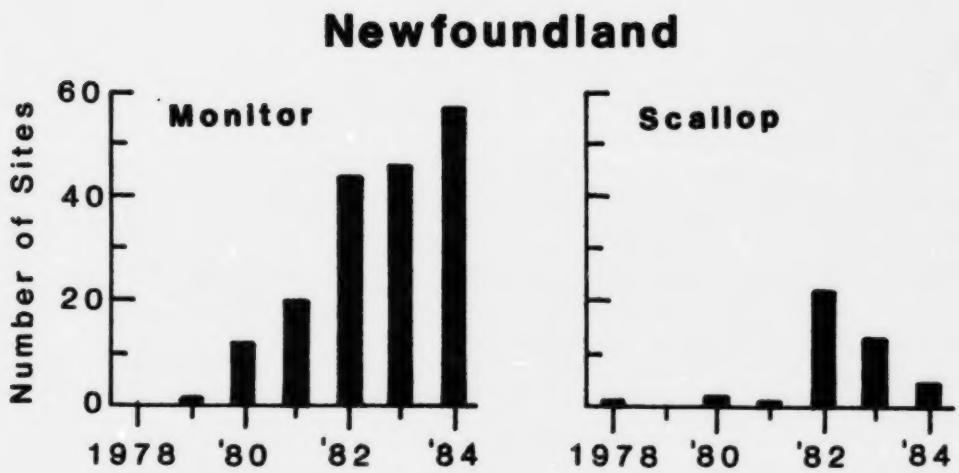


Fig. 29 continued.

Table 3. Summary of use of coastal temperature data (June 13, 1986) compiled by B. Petrie and D. Dobson (AOL, BIO).

DFO Charlottetown	Monitoring of salmonid aquaculture programs for critical factors, mostly extremes, also to identify spawning periods for oysters and mussels (long term).
Memorial University	Monitoring wind forcing effects on water mass movement on Newfoundland east coast to predict zooplankton distribution (short term).
DFO Newfoundland	Arctic char movements from saltwater to freshwater, to establish if temperature is a major factor (long term).
DFO Newfoundland	Herring gill net research, comparison of catch statistics with temperatures (long term).
DFO Newfoundland	Interrelation of meteorological factors and water temperatures for salmon habitat, growing season, and survival rates (long term).
DFO Newfoundland	Lakes and Streams Aquaculture Site, Can. Tech. Rep. Fish. & Aquaculture 1977, Vol. 82 (long term).
DFO Moncton	Herring spawning studies, shellfish production and mortality (long term).
DFO Halifax	All interactions of invertebrates and marine plants where temperature is considered a major factor (long term).
N.S. Dept. Fisheries	Examination of potential and present aquaculture sites for supervision.
DFO Québec	Continuation of long-term surface measurements at Entry Isle, M.I., P.Q.; Grande Riviere, P.Q.; Borden, P.E.I. (20 years earlier data).
DFO Quebec	Biophysical factors triggering migration of cod associated with capelin.
McGill University	Biophysical factors triggering migration of cod association with capelin.
DFO Rimouski	Study of aquaculture site on North Shore. Herring spawning grounds in Gaspe area. Data expected to be part of general requirement for ocean climate study.

.../Contd.

Table 3. .../Contd.

DFO Québec	Estuarine studies for eel migration and post-molt salmon (long term). Correlation of temperature and catch statistics for lobster (paper in preparation) (short term).
Mapaq, MI, P.Q.	Until 1985, lobster stock assessments, growth rate, temperature sensitivity; since 1986, mussel culture sites, one at Carleton, P.Q. (Bay de Chaleur).

southwestern Nova Scotia FEP, and interaction between the Labrador Current Program and studies on northern cod migrations, may result in identification of the key variables and appropriate scales for such monitoring. There is an inherent difficulty in relating results from long-term environmental monitoring programs to changes in the fish populations. The "multiple connectedness" of oceanographic and biological variables is such that in 1 yr the physical variable may be seen to have an apparent direct biological effect, while in another year the same change in the physical variable may have no effect, perhaps because of a difference in another biological variable. Northern cod again provides an example, where the timing of the inshore migration may depend as much on the biomass of young capelin along the edge of the Labrador Shelf as on the temperature and thickness of the cold intermediate layer.

Oceanographic climate-monitoring programs, particularly the sections and fixed-stations programs, have been applied to a variety of problems in fisheries research (see review by Perry and Frank [1987]) although not often in relation to stock assessments. There has been a lack of confidence in their useage since 1975 when aliasing problems were identified in the Halifax section. The analysis of the reliability of the section observations (as useful measures of interannual variability or in identifying trends) by physical oceanographers is considered a high priority by the Newfoundland Region fisheries scientists. They have been pressing for an examination of this sort, particularly on the Flemish Cap section, for many years.

Interannual descriptions of ocean climate can be developed (given appropriate measurement scales), but the problem is how to apply them to fishery studies. In the 1950's, ICES produced synoptic charts of physical properties (temperature, salinity, wind, and nutrients) specifically for the use of biologists (Lee 1984). It was also recommended that the biologists should produce time series of egg production, year-class strength, and fish and plankton distributions for comparison with the physical variables. Apparently, these charts, "...were received with enthusiasm by the biologists, although there is little evidence in the literature of their ever making great use of them" (Lee 1984, p. 12). By 1961, the charts had ceased to be produced, apparently as a result of a lack of enthusiasm amongst biologists, and delays in production. Lee (1984) suggests the major problem with these charts was that they represented surface conditions, while subsurface conditions are more important to fisheries, and that there were large gaps in the area covered; important features like fronts often were not included (i.e. inappropriate spatial scales).

7.4. COMMENTS AND RECOMMENDATIONS

As stated in the introductory section of this chapter, there were divergent opinions within the Working Group on the strategy to be adopted for oceanographic monitoring in relation to long-term changes in fish and invertebrate abundance. Fortunately, recent developments and interests in oceanography may well bring the two points of view together in the near future. Ocean climate research, and thus a focus on the interannual and decadal time scale, is receiving increased emphasis within oceanography as a whole. Fisheries biologists have always been interested in ocean climate (at

least since the turn of the century), but have not had the tools available to adequately describe the oceanographic changes. It appears that the oceanographers themselves may put a high priority on this longer time scale without specific reference to fisheries problems. Nevertheless, there is still an immediate requirement to evaluate the adequacy of the current oceanographic monitoring programs off Atlantic Canada as descriptions of the interannual variability and trends in ocean characteristics.

The Working Group makes the following comments and recommendations:

1. An oceanographic monitoring program is important to many fisheries problems. In most cases, however, the causal relationships influencing the fisheries variable of interest are not understood. Thus, any oceanographic monitoring program should be designed on the basis of physical oceanographic criteria.

2. Existing ICNAF/NAFO oceanographic sections in the Canadian area of interest should be examined by physical oceanographers to determine if the data collected from the sections are detecting interannual variability (i.e. adequate temporal and spatial scales of sampling).

3. The extent and spatial scales over which the Ryan thermograph component of the existing coastal ocean monitoring program is able to detect interannual temperature variability should be quantitatively examined.

4. Subsequent to these examinations an improved (if problems are identified in Recommendations ii and iii) oceanographic monitoring program should be defined (based on oceanographic criteria) as part of an ocean climate program.

CHAPTER 8. SUMMARY AND RECOMMENDATIONS FOR RESEARCH

8.1. SUMMARY

1. The role of physical oceanography in the resolution of fisheries problems in the northern Atlantic has been stressed repeatedly since the turn of the century. The linkages have been addressed specifically in 1899, 1901, 1902, 1913, 1938, 1950, and 1951 within an ICES framework; and 1952/53, 1961, 1964, 1971 and 1981 within ICNAF/NAFO. Results in general have not met expectations. Oceanographic programs have rarely been directed to specific fisheries questions. Rather, the two disciplines have tended to work in parallel. The "big science" initiatives on recruitment in the northwestern Atlantic, which have involved integrated programs, have generated limited increases in understanding. Long-term monitoring of oceanographic properties in important fishing areas has not in most cases received stable institutional support (the Newfoundland program is a notable exception). In those instances where data products were routinely made available, they have not been used often by fisheries biologists. The historical sketch provided perspective for the Working Group. The issues addressed were clearly not new. Why were the results minimal? A recommendation of the ICES Special Meeting on Fisheries

Hydrography in 1951 is perhaps pertinent. Fisheries biologists need to state precisely the problems or questions being addressed; this requires documentation and some detail. The problems subsequently need to be considered as fisheries oceanographic problems, rather than as fisheries initiatives with an added-on oceanographic component. The historical perspective indicated that fisheries problems have rarely been considered to be high-priority oceanographic problems. In addition, hindsight suggests the state of the art in physical oceanography of shelf seas was probably not sufficiently developed prior to the 1970's to realistically expect major advances. This is not the case now; there are good reasons to expect substantial benefits from joint physics-fish studies.

2. Four categories of fisheries problems requiring physical oceanographic information were defined. These are:

   A. Definition of populations

   B. Temporal changes in availability of fisheries resources to either commercial fisheries or research surveys

   C. Causes and short-term prediction of recruitment variability

   D. Long-term changes in abundance levels of exploited populations

   The physical oceanographic requirements for each category are addressed separately.

3. As background information required to aid in the definition, and understanding of the underlying mechanisms, of geographic population patterns a description of the circulation and temperature-salinity characteristics of the Atlantic Canadian shelf is important. In essence an understanding of the oceanographic setting within which species are broken up into relatively isolated self-sustaining populations is considered essential to the development of a full understanding of the mechanisms underlying the definition of populations. Because the life cycles of many species include a seasonal timing, a description of the oceanographic setting on a seasonal basis may be required. Two approaches were taken. First, the relevant time and space scales, and the geographic distribution of archived data, were discussed. The significance of the residual circulation was put into perspective in relation to features of the circulation at shorter time scales (hours, days, months). The residual circulation may be a useless abstraction for the fisheries questions addressed if the circulation at higher frequencies is actually the feature of significance to the organisms. Maps of the distribution of current and temperature-salinity data archived at AOL and MEDS respectively indicate that the spatial and seasonal coverage is generally incomplete. Secondly, gaps in the existing descriptions of the physical oceanographic "setting" were identified. They are substantive. The degree to which both the broad-scale and topographic-scale residual circulations have been described in different parts of the Atlantic Canada shelf seas was summarized. The cross-shelf structure and seasonal variability in the

broad-scale, along-shelf flow is not well described, with the exception of the Cape Sable region off southwestern Nova Scotia. The information is lacking particularly for the entire Newfoundland shelf. The topographic-scale circulation has been described for only a small fraction of the shelf. The most detailed descriptions were the clockwise circulations around Browns and Georges Banks. There is very little information on the seasonality of the circulation patterns over the offshore banks on the northern Labrador Shelf, on the Newfoundland Shelf south of Newfoundland, and on most of the Scotian Shelf. There is also very little information on the circulation patterns and their seasonality in the bays on the eastern and southern coasts of Newfoundland.

There have been several analyses of the large-scale distribution of sea-surface temperature on the Atlantic Canadian shelf. The depth range for which the surface temperatures are representative is not well understood. Some description of the seasonal variability in the distribution of subsurface temperature and salinity is available or becoming available for all regions of the Atlantic Canada shelf. The available descriptions are generally based on only a fraction of the existing data base and generally only resolve the broad-scale and large-scale patterns. There is a noticeable lack of interpretive descriptions of the water mass properties on the Newfoundland Shelf.

4. The existing physical oceanographic information pertaining to the interannual variability in the migration of northern cod between the inshore and offshore areas off eastern Newfoundland and Labrador, as well as the physical oceanography of this geographic area, was summarized. Some hypotheses accounting for the changes in availability of northern cod to the inshore fishery were listed. Finally, current relevant research activities in oceanography were described.

   The analyses to date of the oceanographic and cod catch data provide some support for the leading hypothesis (i.e.,

   > "...the proportion [of cod] migrating to shallow inshore water may vary with the temperature or thickness of the core of the Labrador Current. The proportion should increase with increasing temperature and decreasing thickness of the core of the Labrador Current").

   The available physical oceanographic information on the immediate area of interest comes primarily from hydrographic data. The hypothesized influences, however, may be associated with larger-scale variability in the Labrador Current and the hydrographic structure of the shelf areas as a whole. Thus, existing moored measurements from the Hamilton Bank area, Avalon Channel, the Hibernia region, and Trinity Bay are likely to be of relevance to the northern cod availability problem. The AOL investigation of variability in sea ice on the Labrador and Newfoundland Shelves is also of relevance. A detailed research project is outlined to test the leading hypothesis and generate explanations and some capability for short-term prediction of changes in availability.

5. The available physical oceanographic information pertaining to the interannual variability in silver hake migration onto the Scotian Shelf was summarized. It has been suggested that the timing of the spawning migration of the silver hake that overwinter along the shelf edge may depend on the warming of the shelf waters shoreward of the SMGL and of the waters along the shelf edge, either through a direct temperature influence or a temperature effect on the silver hake's maturation.

   The summary and analyses of the physical oceanographic data indicate that the Scotian Gulf area is one of the more intensively studied parts of the Atlantic Canadian shelf. The observations indicate that the hydrography and current structure are complex, and reveal that the dominant subtidal variability in the lower water column is associated with wind events and offshore variability (periods of weeks to months) rather than the seasonal heating cycle. The existence of a seasonal variation in bottom water temperature, as implied by the suggested temperature influence on the timing of the silver hake's on-shelf migration, has not been established. This raises the possibility that the hake's migration may be associated with wind- and eddy-induced events, rather than seasonal changes.

   Some explanatory statistical analyses were carried out to investigate possible relationships between catch rate of silver hake and oceanographic indices. The analyses have not revealed statistically significant relationships between the silver hake catch rates south of the SMGL and shelf bottom temperatures. It is not clear that the temperature observations used are appropriate to the hypothesized influence on timing of the hake's migration. Furthermore, the spatial extent and seasonal variability of the water with temperatures favourable to silver hake have not been determined using the historical data base. Finally, the most extensive summary of the seasonal variability in the distribution of temperatures on the Scotian Shelf is based on bottle data only, thus using only a fraction of the existing data.

   Some approaches designed to more fully utilize the available data to address the silver hake availability problem are outlined. A major oceanographic field program is not considered necessary at this stage.

6. The ICNAF/NAFO Georges Bank herring program involved a recruitment component. In 1975 it was recommended, in relation to recruitment variability of Georges Bank-Nantucket Shoals herring, that three aspects of the overall problem be addressed (the circulation and mixing processes above and around the Bank, a "patch study" to identify the physical processes responsible for larval loss from the system, and studies on the primary and secondary productivity of the Bank). The first two studies were subsequently carried out. Because of the rapid decline in the abundance of herring prior to the patch study, chaetognath distributions rather than distributions of herring larvae were analysed. Even though the results of the patch study were not analysed and presented in a timely fashion, and the oceanographic data are not yet fully analysed, the advantages of sophisticated joint field studies (i.e. physical oceanographic measurements made specifically in relation to a fisheries biology sampling program) are clear.

In 1961 Flemish Cap fish populations were first considered well suited for recruitment studies. Interannual variability in circulation and mixing over and around the Cap was hypothesized to be critical to the definition of year-class sizes. As such the physical oceanographic component of the Flemish Cap recruitment study initiated in 1978 was important to the success of the overall program. However, the success of the physical oceanographic program was severely hampered by a low recovery rate of the moored instrumentation. Further, the physical oceanographic observations that were taken have not been adequately analyzed and interpreted. At the 1986 NAFO Special Scientific Meeting on the Flemish Cap and other recruitment studies, there was no analysis of the relevant physical oceanography for the Flemish Cap.

From hindsight the Working Group concluded that the physical oceanographic components of both of the major recruitment studies (Georges Bank herring and Flemish Cap cod/redfish) were not given sufficient priority. In the Georges Bank study the oceanographic field experiments were relatively substantive and were planned jointly with the fisheries biologists but appear to have suffered from the lack of specific physical oceanographic hypotheses and stand-alone capability. Analysis of the data, however, received a low priority. In the Flemish Cap study the oceanographic component appears to have been largely exploratory in nature and was crippled by equipment losses, but again analysis of the returned data received a low priority. The Browns Bank haddock study, which is at the analysis stage, involved both substantive prior physical oceanographic research and considerable joint research involving oceanography and fisheries biology. It is premature to evaluate the contribution of the oceanographic research to the resolution of the fisheries questions.

7. The IREP initiative by the IOC indicates that the overall recruitment problem has been defined as a high-priority oceanographic research area. ICES has been requested to generate and coordinate IREP initiatives in the northern Atlantic. A major theme of IREP is that comparative studies of different populations of the same or similar species, over relatively short time periods, may lead to substantive increases in understanding the processes involved in generating recruitment variability. The Working Group identified two species that should benefit from a comparative approach, both involving a significant physical oceanographic component. These involve comparative studies of: 1) cod recruitment in coastal currents (Labrador, Iceland, Norwegian coastal currents); and 2) scallop recruitment to diverse fished aggregations in the Gulf of Maine area. In the former the emphasis is on understanding the underlying mechanisms controlling the interannual variability in the circulation of coastal currents and the role of freshwater runoff in this process. The physical oceanographic aspects of such a study require considerably more evaluation than has occurred at this stage prior to evaluating the tractability of this problem. The emphasis in the latter is placed in evaluation of the role of physical processes in defining the horizontal scale of larval dispersion from diverse spawning aggregations. A third example deserving particular attention but which does not involve a comparative approach is recruitment variability in

lobsters in the Magdalen Islands area. Recruitment is well predicted by RIVSUM during the first year of life. Prior to the development of hypotheses concerning the underlying mechanisms, an understanding of the effects of differences in runoff on the circulation and mixing around the Islands in question is required.

8. There were two points of view of the appropriate approach for monitoring physical oceanographic properties in relation to long-term changes in abundance of commercially exploitable populations. One view considered it important to be able to describe the environment on an interannual time scale without necessary reference to a particular fisheries problem. The other view argued that monitoring should not be defined without reference to a specific fisheries problem. Identification of the fishery problems and their appropriate physical oceanographic requirements were viewed as integral steps in establishing appropriate monitoring strategies. In essence, monitoring should follow process-oriented studies that have generated understanding of causal linkages between fluctuations in fisheries and oceanographic processes. The two points of view are not necessarily mutually exclusive. Fisheries-problem-specific monitoring could be part of a broader-based ocean climate monitoring program. Existing long-term physical oceanographic monitoring programs were summarized. These include sea level, coastal sea-surface temperature, the hydrographic sections program, and variability of transport by the Labrador Current. Deficiencies with the hydrographic sections program were discussed. The Halifax line was discontinued in 1977 because it was determined that with only four surveys per year the data were inappropriate to detect interannual variability. The other sections have not yet been evaluated. The coastal temperature program has been supplemented by Ryan thermographs in recent years. Their ability to detect interannual variability in temperature, however, has not been evaluated. The Labrador Current monitoring study should be very useful to fisheries problems in the Labrador Shelf/Grand Banks area when the data are analysed and interpreted. The existing long-term monitoring data have been used in the analysis of diverse fisheries problems, in particular in retrospective analyses of recruitment variability and trends in landings. The oceanographic data have been used in this way to generate hypotheses concerning the linkages between population fluctuations and oceanographic processes. The data have not been used extensively in stock assessments. There has been a lack of confidence in using the data from the hydrographic sections because of the potential aliasing problems. There is an immediate requirement to evaluate the adequacy of the current oceanographic monitoring programs off Atlantic Canada as descriptions of the interannual variability and trends in ocean characteristics.

In the past the oceanographic sections program of ICNAF and the coastal hydrographic observations made by the Department have been established and maintained in relation to perceived fisheries needs. The observational programs have frequently been criticized as being inadequate for a description of long-term variability of shelf-water oceanographic conditions. They are nevertheless the only data sets available for this important time scale of events and are frequently used

in exploratory analyses of fisheries variability (Sutcliffe and Koslow [1984] type approach). What minimal observational program is required to say anything about long-term changes in the oceanographic environment? This question needs a response, with heavy input from physical oceanographers. Subsequent to a definition of minimum observational requirements to describe decadal time-scale fluctuations in oceanographic properties in Atlantic Canada's shelf seas the programs need to be institutionalized.

9. The Working Group made some general comments. Progress in understanding both the causes of availability changes in fisheries (Category 2) and recruitment variability (Category 3) requires a multidisciplinary research team, but with stand-alone components. There is a need for increased emphasis on the analysis of existing physical oceanographic data and the publication of descriptions of the physical environment in areas of importance to Atlantic Canadian fisheries. In joint studies, timely publication of the oceanographic data is important. In the past joint studies which have floundered, the research managers do not appear to have adequately pushed the programs ahead. Joint accountability at the management level for multidisciplinary projects involving more than one line management is required. Permanent working groups by region would be one mechanism to facilitate linkages between physical oceanographers and fisheries biologists. Alternatively, present mechanisms within CAFSAC, NAFO, and ICES could be strengthened. Finally, it is noted that current funding levels for physical oceanogrpahy seriously limit the progress that can be made on fisheries problems.

8.2. RECOMMENDATIONS FOR RESEARCH

The recommendations are grouped under the four categories of fisheries questions requiring oceanographic input. They are stated in a brief form here. The appropriate text in earlier chapters should be consulted for elaboration or clarification.

A. Definition of Populations (Chapter 4)

It is recommended that,

A1. The appropriate criteria for the determination of the significance of the means and seasonal cycles of currents, temperature, and salinity required by the first category of fisheries questions be addressed for the species studied in the Fisheries Ecology Program in the Browns Bank area. The importance of measures of the variability about the means and seasonal cycles should be evaluated.

A2. The space scales of the current, temperature, and salinity distributions on the Atlantic Canadian shelf be examined quantitatively for some representative regions using objective analysis techniques and that the factors which determine those scales be determined.

A3. Given that the available information on the means and seasonal circulation on the topographic scale is grossly inadequate for the region as a whole, fisheries scientists priorize on an area-by-area

basis their requirement for descriptions of the seasonality of circulation patterns.

A4. The long-term means and seasonal cycles of the local along-isobath and cross-isobath components of the monthly mean current be determined for existing records extending over 1 yr or more, and that the means and seasonal cycles of the standard deviations about the monthly means be determined for the along-shelf and cross-shelf components of subtidal current for these records.

A5. The monthly means of temperature and salinity (averaged over all years), standard deviations, and numbers of observations for standard depths and subareas corresponding to topographic features be calculated using the merged MEDS data base.

A6. The merged MEDS data base be used to develop monthly maps of the bottom temperature and its variability averaged over all years for the entire Atlantic Canadian shelf.

A7. Fisheries scientists priorize the areas and seasons for which seasonal descriptions of temperature and salinity distributions are required, and where possible state the minimum seasonal and spatial variations in the required parameters that would be significant to the fisheries questions.

A8. The seasonal variation of the integrated (across the shelf) along-shelf transport be examined for locations from which moored measurements are available, and that the results of this analysis be used in a review paper summarizing the evidence for continuity of the broad-scale flow throughout the region and the consistency of the seasonality observed on the various cross-shelf sections.

A9. There be an intercomparison and assessment of the FNOC, NCC, and MEDS data bases of sea-surface temperature for the Atlantic Canadian shelf.

A10. Those data bases that are judged reliable be combined and used in an objective analysis of the spatial distribution of sea-surface temperature on the Atlantic Canadian shelf by month (average over all years).

A11. There be a study to determine the fraction of the water column for which sea-surface temperatures and their anomalies are representative.

A12. The present MEDS effort toward creating a merged data base of oceanographic bottle, bathythermograph, and CTD observations be supported.

B. Temporal Changes in the Availability of Fisheries Resources to Either Commercial Fisheries or Research Surveys (Chapter 5)

Northern cod: It is recommended that,

B1. Analysis of existing data (specifically 1] the hydrographic data from the Hamilton Bank, White Bay, Cape Bonavista, and St. John's [47°N] sections; and 2] the time series of hydrographic data from the Hamilton Bank and Station 27) be given first priority, and that any field study be designed on the basis of the results of that analysis, advice from scientists presently conducting the field studies of Labrador Current variability, and the considerations and suggestions outlined in this report.

B2. The research program outlined on p. 61/62, Point 5, should be complemented by the development of conceptual models for the formation and evolution of the cold intermediate layer and for the response of the inner northeastern Newfoundland Shelf to wind stress forcing, and that these models be developed prior to any major field program so that they can be used in the detailed experimental design and formulation of specific physical oceanographic hypotheses.

B3. Given that satellite infrared imagery can provide valuable synoptic information on the sea-surface temperature distribution in the area of interest, particularly of the occurrence of coastal upwelling, this sampling tool should be used to complement any field study.

B4. Any physical oceanographic field program along the lines of that suggested in this report also be complemented by concurrent hydroacoustic surveys and tagging experiments aimed at describing the extent, route, and timing of the migration of northern cod in relation to the description of the physical environment.

B5. Any physical oceanographic investigation of the cold intermediate layer should also be used to identify a long-term monitoring strategy of the layer's features that are considered to influence the availability of northern cod.

Silver hake: It is recommended that,

B6. The spatial extent and seasonal variability of bottom water on the Scotian Shelf and Slope with temperature in the range favourable to silver hake be determined using the entire MEDS data base.

B7. The moored temperature measurements made during the 1975-78 AOL program be examined for evidence of seasonal variability in the Scotian Gulf, Emerald Basin, and shelf-break areas.

B8. Available data on silver hake distributions and migration be examined in relation to the physical oceanographic observations and descriptions for the years (1967-68, 1976-77) in which the AOL measurement programs were carried out.

B9. A leading hypothesis for a temperature influence on the timing of migration be identified prior to any field investigation.

B10. Any field program directed toward examining a temperature influence on the timing of silver hake migration be designed in conjunction with physical oceanographers familiar with existing observations from the area.

B11. Further correlation analyses be carried out involving the existing CPUE data and physical oceanographic indices for: 1) the position of the shelf-water/slope-water front and the number of warm-core rings obtainable from sea-surface temperature charts, 2) the Gulf of St. Lawrence outflow, and 3) the wintertime mixed layer depth and temperature on the Scotian Shelf and in the Gulf of St. Lawrence.

B12. The relation found by Garcia (1981) between area of warm water and temperature at one site in the Saddle be critically examined using available data.

C. Causes and Short-Term Prediction of Recruitment Variability

It is recommended that,

C1. Any major Departmental initiative involving recruitment be conceived and planned as an oceanographic program as much as a fisheries biology program. The physical oceanographic components of the program should be given a high priority, and the scientists involved should have a stake in its success or failure.

C2. Canada take the lead in initiating a comparative study of the interannual variability in the circulation of coastal currents having cod populations (Labrador, Iceland, and Norwegian coastal currents). The study could be a contribution to IREP.

C3. A comparative recruitment study be carried out on sea scallops. The primary aim of the study would be to evaluate the horizontal scale of dispersion of scallop larvae from different commercially important aggregations (populations?). The study could contribute to an understanding of the source of recruitment rather than the annual variability.

C4. A recruitment study on Magdalen Islands lobsters be carried out. Initially, it is necessary to evaluate the influence of freshwater runoff from the St. Lawrence drainage system on downstream circulation and mixing around the Magdalen Islands. The initial physical oceanographic study is required prior to the definition of hypotheses underlying the statistical relationship between river runoff and lobster landings in the Magdalen Islands.

D. Long-Term Changes in Abundance Levels of Exploited Populations

It is recommended that,

D1. Existing ICNAF/NAFO oceanographic sections in the Canadian area of interest should be examined by physical oceanographers to determine if the data collected from the sections are detecting interannual variability.

D2. The extent and spatial scales over which the Ryan thermograph component of the existing coastal ocean monitoring program is able to detect interannual temperature variability should be quantitatively examined.

D3. Subsequent to these examinations an improved (if problems are identified in Recommendations D1 and D2) oceanographic monitoring program should be defined (based on oceanographic criteria) as part of an ocean climate program.

ACKNOWLEDGEMENTS

We wish to thank numerous colleagues for discussion and input on the topics covered in this report. In particular, we thank K. Drinkwater, B. Petrie, P. Smith, J.E. Stewart, and R.W. Trites for critical reviews of a draft version of the report; J. Gagnon and D. Gregory for providing Figures 3 to 10 and 2 respectively; J. Richard for data analysis in Chapter 5.2; J. Pritchard for drafting assistance; S.P. LeBlanc for editing and preparing the overall manuscript; and V. Wood for typing parts of preliminary drafts.

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LIST OF ACRONYMS REFERRED TO IN REPORT

AOL	Atlantic Oceanographic Laboratory (of the Bedford Institute of Oceanography, Department of Fisheries and Oceans, Dartmouth)
ARDC	Atlantic Research Directors Committee (of the Department of Fisheries and Oceans)
BIO	Bedford Institute of Oceanography (Dartmouth)
CAFSAC	Canadian Atlantic Fisheries Scientific Advisory Committee (of the Department of Fisheries and Oceans)
CPUE	Catch Per Unit of Effort
CTD	Conductivity, Temperature, Depth sampling device
DFO	Department of Fisheries and Oceans
DM&TS	Department of Mines and Technical Surveys
FAO	Food and Agriculture Organization of the United Nations
FEP	Fisheries Ecology Project (multidisciplinary program primarily on haddock population biology in the Browns Bank area)
FNOC	Fleet Numerical Oceanography Center (United States)
FRB	Fisheries Research Board
ICES	International Council for the Exploration of the Sea
ICNAF	International Commission for the Northwest Atlantic Fisheries
IGOSS	Integrated Global Ocean Services System
IOC	Intergovernmental Oceanographic Commission
IREP	International Recruitment Project
LIMEX	Labrador Ice Margin Experiment (research project of the Atlantic Oceanographic Laboratory)
MEDS	Marine Environmental Data Service (Department of Fisheries and Oceans, Ottawa)
MEL	Marine Ecology Laboratory (former research structure within the Bedford Institute of Oceanography)
NAFC	Northwest Atlantic Fisheries Center (Department of Fisheries and Oceans, St. John's)
NAFO	Northwest Atlantic Fisheries Organization

NCC	National Climate Center (United States)
OSLR	Ocean Science in Relation to Living Resources
RIVSUM	Estimates of runoff from the St. Lawrence drainage system as far downstream as the Saguenay Fjord (as defined by Sutcliffe 1973)
SMGL	Small Mesh Gear Line (line on the Scotian Shelf/Slope used for fisheries management regulations)

Appendix 1. Research program in oceanography and fisheries biology proposed at the first planning meeting for ICES in 1899

Programme pour le travail hydrographique et biologique dans les aires septentrionales de l'Océan Atlantique, dans la Mer du Nord, la Baltique et les mers adjacentes.

Les lignes principales de ce programme, lequel est communiqué plus loin, in extenso, avec les additions et amendements introduits au cours de l'année suivante et jusqu'en 1927, comprenaient:

L'établissement d'un Conseil international permanent pour l'exploration de la mer, comprenant deux délégués de chaque pays lesquels éliraient le président, le vice-président, le secrétaire général et les suppléants et établiraient les statuts et l'ordre des travaux de cette institution;

une statistique de la pêche qu'on s'efforcerait de dresser pour les pays participants d'après des principes adoptés en commun;

l'établissement d'un laboratoire central pour les recherches physiques et chimiques se rattachant à l'exploration de la mer;

l'étude synoptique de la mer pendant toutes les saisons au moyen de voyages périodiques sur tout le territoire des recherches.

A. Travail hydrographique.

I.

Les recherches hydrographiques doivent avoir pour objet: la distinction des différentes couches d'eau selon leur distribution géographique, leur profondeur, leur température, leur salinité, le contenu de gaz, le plancton et les courants, afin de trouver les principes fondamentaux, non seulement pour la détermination des conditions extérieures pour les animaux de mer utiles, mais aussi pour les prédictions météorologiques de périodes étendues dans l'intérêt de l'agriculture.

II.

Comme les conditions hydrographiques sont sujettes à des changements saisonniers, et comme ceux-ci influencent sérieusement la distribution et les conditions d'existence des animaux de marine utiles et l'état du temps et des autres conditions météorologiques en général, il est désirable que les observations soient faites autant que possible simultanément pendant les 4 mois typiques février, mai, août et novembre sur certains points définis le long des mêmes lignes déterminées.

III.

Les observations dont il est question dans l'article II seraient:

a) Observations sur la température, l'humidité et la pression atmosphérique toutes les deux heures, en employant les instruments automatiques d'enregistrement pour l'interpolation et l'aspirateur de Assmann.

Les bureaux météorologiques doivent avoir l'occasion de faire à bord des vaisseaux des observations physiques dans les niveaux élevés de l'atmosphère au moyen de cerfs-volants.

Les autres observations météorologiques doivent être faites selon les méthodes adoptées par les bureaux météorologiques des nations représentées.

Les observations météorologiques et hydrographiques faites à bord des steamers spéciaux au cours de la surveillance pendant les mois typiques, doivent être immédiatement notées sous l'inspection du bureau central (voir C.) pour la publication dans un bulletin où les conditions maritimes et atmosphériques doivent être représentées par des tables et des tableaux synoptiques en coopération avec les institutions météorologiques des nations représentées.

b) La température de la surface de l'eau doit être prise toutes les deux heures et même plus fréquemment si c'est nécessaire. Il est désirable que des appareils automatiques d'enregistrement soient employés pour l'interpolation.

Les observations sur la distribution verticale de la température doivent être faites aux points mentionnés à l'article II et doivent être faites régulièrement à des intervalles de 0, 5, 10, 15, 20, 30, 40, 50, 75, 100, 150, 200, 250, 300, 400 mètres et ainsi de suite; mais toutes les parties critiques de la courbe doivent être déterminées par des études supplémentaires.

La température du fond doit être examinée avec tout le soin possible.

c) A chaque point et à chaque profondeur où la température est observée, il faut prendre un échantillon de l'eau pour en déterminer la salinité et la densité.

Par salinité, on comprend le poids total en grammes de la matière solide dissoute dans 1000 grammes d'eau.

Par densité, on comprend le poids en grammes[1]) de 1 cm cube d'eau d'une température in situ $t°$, c. à d. la gravité specifique in situ référant à l'eau pure de + 4° C. $\left(= S\frac{t°}{4°}\right)$.

Pour la gouverne, il faut ajouter, qu'une détermination préliminaire de la salinité doit être faite à bord avec les instruments convenables, mais la détermination exacte de la salinité et de la densité de tous les échantillons doit avoir lieu dans un laboratoire scientifique.

d) A certaines profondeurs des points mentionnés à l'article II, ainsi qu'ailleurs à la surface, il faut collectionner des échantillons d'eau pour l'analyse des gaz constituants (oxygène, nitrogène et acide carbonique).

IV.

Pour les mesures de profondeur, l'unité adoptée doit être le mètre, mais en même temps la profondeur peut aussi être exprimée en brasses.

Les points géographiques doivent se référer à la longitude de Greenwich, et les distances horizontales doivent être exprimées en milles (= 1852 mètres).

Les thermomètres employés pour la détermination de la température de la surface doivent être centigrades ou Fahrenheit, mais pour la publication, tous les chiffres doivent être réduits en centigrades.

Dans les thermomètres centigrades, la distance entre les marques de degrés doit être d'au moins 5 mm et le degré divisé au moins en 2 parties; le thermomètre Fahrenheit doit être divisé d'une manière correspondante.

L'emploi des bouteilles à eau isolées de PETTERSSON est recommandé pour les profondeurs modérées et les thermomètres employés pour cet appareil doivent avoir un espace d'au moins 10 mm entre les marques d'un degré et le degré doit être divisé en 10 parties.

Pour les plus grandes profondeurs de l'océan, il faut employer des thermomètres Negretti-Zambra ou d'autres de ce même type.

Le verre employé pour les thermomètres, et les thermomètres eux-mêmes, doivent être vérifiés et approuvés par le bureau central (voir C. a.).

Pour la détermination de la salinité et de la densité, on peut adopter des méthodes physiques ou chimiques, à condition que la salinité puisse être déterminée avec une justesse de 0,05 dans un millième (et la densité jusqu'à 0,00004).

La détermination de ces états peut être fondée soit par l'analyse chimique de l'halogène par poids ou titre, soit par la détermination physique de la gravité spécifique au moyen de pycnomètres de balance hydrostatique et d'hydromètres à condition que les mesures soient prises en excluant les troubles produits par des effets thermaux, la capillarité, la viscosité, etc.

L'analyse chimique doit être contrôlée par des méthodes physiques, et les déterminations physiques par l'analyse chimique, de la manière suivante:

[1]) Les unités de poids doivent être employées ici au lieu des unités de quantité.

Trois échantillons au moins de chaque collection examinée doivent être choisis et envoyés au bureau central. Des **échantillons standard** seront envoyés en échange [1]).

La **gravité spécifique** doit être représentée dans les tables par la formule $S\,(^{0°}_{4°})$.

V.

Les échantillons pour l'analyse des gaz doivent être collectionnés chaque fois dans une couple de tubes vacuum stérilisés.

Il est à désirer que les tables existantes de l'absorption du nitrogène et de l'oxygène soient revisées.

VI.

Des observations qualitatives du plancton doivent être faites toutes les six heures en passant l'eau à travers un filet de soie pendant l'espace de 15 minutes, et, en même temps, on doit prendre un échantillon de l'eau (III. c.).

Aux points mentionnés à l'article II, il faut collectionner, selon la méthode du professeur HENSEN, des échantillons pour l'analyse quantitative, à différentes profondeurs suivant les circonstances hydrographiques.

On recommande la modification de PETERSEN pour le filet de HENSEN.

Des observations sur la transparence et la couleur de l'eau doivent être faites aux points mentionnés à l'article II.

Il faut donner aux institutions bactériologiques l'occasion d'exécuter des investigations dans l'océan.

VII.

Les observations sur les courants et les marés doivent être faites aussi souvent que les circonstances le permettent.

Les courants doivent être examinés, si possible, par des courant mètres directs et par des trains de bois pour la surface et les eaux intermédiaires et par des bouteilles traînants sur le fond.

Le bateau doit être ancré par occasion pour permettre de fréquentes observations pendant une période de marée complète.

VIII.

Il est désirable que l'on fasse une carte du fond de mer examiné pour en montrer la nature.

La description des dépots doit être faite sur un plan défini pour être fixée plus tard.

IX.

Les observations normales doivent être faites le long des lignes provisoirement dessinées sur la carte annexée où *R* signifie russe, *F* finnois, *S* suédois, *G* allemand, *Da* danois, *Du* hollandais, *N* norvégien et *B* les lignes britanniques en février, mai, août et novembre. Chaque pays participant devrait fournir, dans ce but, un navire d'exploration organisé pour des recherches hydrographiques et biologiques, dans l'intérêt de la pêche.

Le plan de ces voyages périodiques se trouve exposé sur la carte suivante:

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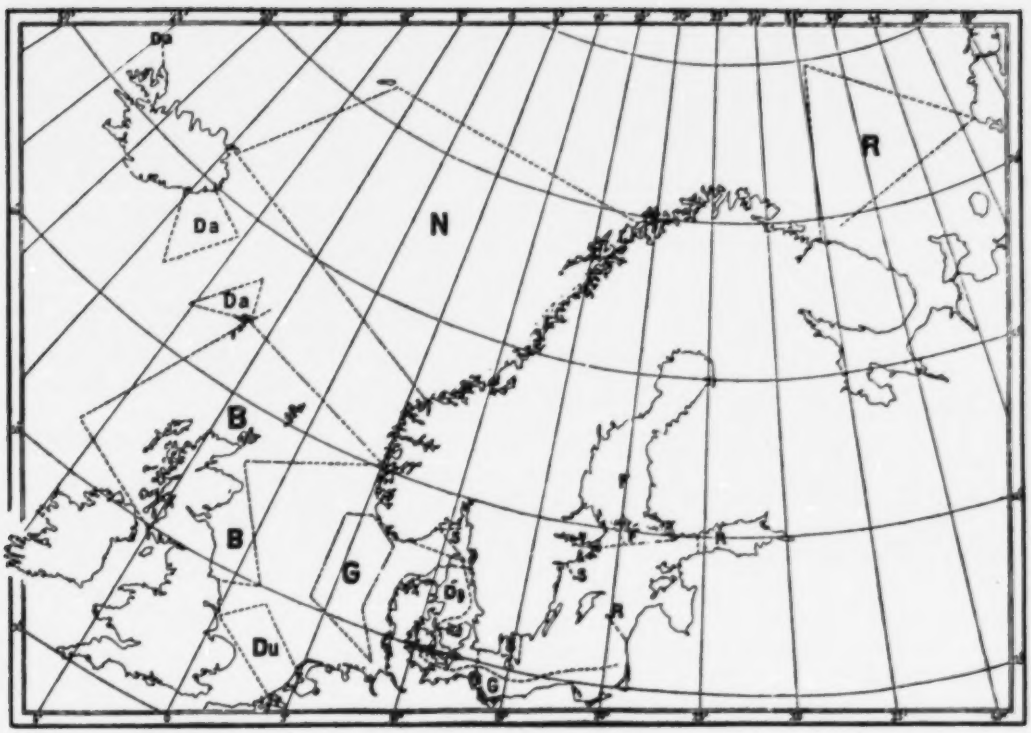
[1]) Par eau **standard**, on comprend des échantillons d'eau de mer filtrée, dont les propriétés physiques et chimiques sont connues avec le plus de justesse possible grâce à l'analyse, et dont le rapport est envoyé aux différents laboratoires en même temps que les échantillons. A l'égard de l'halogène les échantillons d'eau ordinaire doivent être comparés à l'eau standard à l'aide de méthodes analytiques.



Les points spéciaux doivent être décidés par les nations respectives, et une fois choisis, les observations subséquentes doivent y être répétées.

Les instructions particulières pour les stations seront données par les nations respectives et les communications sur l'étendue et la nature des observations auront lieu par l'intermédiaire du bureau central. (Voir C., a et c.)

X.

Il est désirable d'employer pour l'exécution de ces recherches des navires routiers réguliers, des bateaux-phares, etc., et des stations de la côte lorsqu'il s'agit de faire des observations sur la température et de collectionner les échantillons d'eau de mer et de plancton.

Ces observations ne doivent pas seulement être faites dans les mois typiques, mais aussi durant les périodes intervallaires.

B. Travail biologique.

I.

a) Détermination de la distribution topographique et bathymétrique des œufs et des larves des poissons de mer utiles, par exemple, par des méthodes quantitatives comme celles de HENSEN, et en référant spécialement les espèces les plus importantes comme la plie, la morue et l'églefin, le hareng, etc.

b) Investigation continue sur la vie et les conditions de vie des jeunes poissons d'espèces utiles dans leurs stages postlarvaux et jusqu'au moment de leur maturité en faisant une référence spéciale de leur distribution locale.

c) Observation systématique des poissons de vente à l'état de maturité en ce qui concerne les variétés locales et les migrations, leurs conditions de vie, leur nourriture (par exemple en examinant le contenu de leur estomac) et leurs ennemis naturels, c'est à dire des observations sur la présence et la nature de la nourriture des poissons au fond de la mer, à la surface et dans les eaux intermédiaires à une profondeur d'au moins 600 mètres.

d) Détermination des variations périodiques dans la présence, l'abondance, et la taille moyenne des poissons utiles, et leurs causes.

II.

a) Pêches expérimentales dans les aires de pêche connues à l'époque de la pêche, ainsi qu'en dehors de ces aires et à d'autres époques.

b) Préparations de statistiques uniformes du résultat de ces pêches, indiquant en détail le nombre, les espèces, la taille, le poids et la condition du poisson: par exemple comme la "Scottish Fishery Board" l'a fait à bord du "Garland".

c) L'emploi uniforme d'instruments appropriés à la pêche expérimentale de poissons de différentes espèces et de différentes tailles.

d) Le marquage expérimental et la libération du poisson, par exemple, de la plie, en aussi grande quantité que possible et dans des aires étendues, comme l'ont fait par exemple le Dr. C. G. Joh. Petersen et le Dr. T. W. Fulton (Rapports de la station biologique du Danemark et de la "Scottish Fishery Board") et d'autres encore.

III.

a) Il est désirable de collectionner des statistiques uniformes sur le nombre, le poids et la valeur du poisson capturé, sur les moyens employés pour la pêche et sur les gens qui s'y consacrent, comme par exemple dans les Rapports généraux de la "Scottish Fishery Board".

b) Il faut collectionner du matériel pour la préparation de cartes indiquant les aires de pêche et la sorte de pêche qui y est faite. (Voir A.VIII.)

C. Organisation d'un Bureau Central.

I.

La réunion recommande que pour les recherches hydrographiques et biologiques de la mer il y ait un conseil international avec un bureau central pourvu d'un laboratoire. Les fonctions du bureau central seraient:

a) de donner des directions uniformes pour les recherches hydrographiques et biologiques en accord avec les résolutions prises dans le programme de la réunion présente, ou en accord avec les modifications qui peuvent y être introduites plus tard avec le consentement des Etats représentés,

b) de contrôler les instruments et d'assurer l'uniformité des méthodes,

c) d'entreprendre les travaux particuliers qui peuvent lui être confiés par les Gouvernements participants,

d) de publier des rapports périodiques et des journaux qui peuvent se montrer utiles pour l'exécution du travail coopératif,

e) de décider la représentation graphique, les échelles, les signes et les couleurs à employer pour les cartes afin d'obtenir l'uniformité pour les publications,

f) de se mettre en rapport avec les administrations des télégraphes dans le but d'obtenir, de temps en temps, régulièrement, les déterminations des changements de résistance des câbles qui traversent les aires dans toutes les directions.

Appendix 2. Resolutions stressing the importance of physical oceanography to fisheries problems at the 1938 ICES Statutory Meeting

Report and Recommendations of the Consultative Committee.

Chairman: Professor Johan Hjort

The Committee met on May 23rd, 1938, at 11.00 a.m., on May 25th at 4.30 p.m. and on May 27th at 4.00 p.m.

3. Hydrographical and Biological Investigations.

It was recommended:

(a) That Mr. SANDSTROM, who has now lectured on the meteorological problems connected with the study of the sea, shall, if he so desires, submit a report on this aspect of the work to the Advisory Committee, appointed in 1936, to assist him, and continue his work on the outstanding hydrographical problems.

(b) That a Sub-Committee of hydrographers and biologists shall be appointed to discuss a plan of combined hydrographical and biological investigations in future, especially with regard to the fluctuations of the conditions of life in the sea. The Sub-Committee should consist of Drs. KNUDSEN, GRAN, LE DANOIS, SCHULZ, and KEMP. This Sub-Committee should meet at a convenient time before the next meeting of the Council and should report to a larger Committee of whom the members should be, in addition to these five, Drs. H. PETTERSSON, DEFANT, STEEMANN NIELSEN, F.S. RUSSEL, SUND, and HENTSCHEL. It is understood that this Committee will keep in touch with the biologists of the Council who are experts in the study of fish and will have recourse to their assistance. It is further understood that they are at liberty to enlist a co-operation of experts from outside the Council such as for instance Dr. H.B. BIGELOW and Captain ISELIN.

4. Scientific Meetings.

It was agreed:

That the subject for the Scientific Biological Meeting next year should be the study of the relation between catch and intensity of fishing discussed from both a theoretical and a practical standpoint, and the question of holding a Scientific Meeting relative to Hydrography and Plankton should be at the discretion of the President.

That Prof. M. SIEDLECKI be asked to prepare a plan, to be discussed next year, for a Scientific Meeting on Fish Migrations.

That the papers prepared for this year's Scientific Meetings be published in the series Rapports et Procès-Verbaux, as Vol. No. 108.

15) Mr. SANDSTRÖM gave a lecture on his work.

Prof. KNUDSEN said that the Committee had first to discuss the report given by Mr. SANDSTRÖM and secondly the proposals put forward in memoranda (see III, P.M.) from Prof. HJORT, Prof. GRAN, Dr. ANDERSSON and Mr. SANDSTRÖM for combined biological and hydrographical investigations.

Prof. HJORT proposed that the report of Mr. SANDSTRÖM should be taken *ad referendum* and that the appointment of a Committee to be nominated by the Consultative Committee to consider plans for a combined biological and hydrographical investigation of the Atlantic water should be considered. The appointment of such a Committee was discussed and the following were suggested as members of the Committee — GRAN, LE DANOIS, BIGELOW (failing him ISELIN), KNUDSEN, DEFANT (failing him SCHULZ), HANS PETTERSSON, STEEMANN NIELSEN, F. S. RUSSELL, HENTSCHEL and SUND[2]).

The Hydrographical Committee agreed that SANDSTRÖM's work should be continued and that, when finished, it should be laid before the relevant Sub-Committee (KNUDSEN, DEFANT, ZEILON) before it was transmitted to the Editorial Sub-Committee[1]).

16) Prof. KNUDSEN was re-elected Chairman of the Committee.

II. Recommendations.

I a) In view of the fact that the "Association Internationale d'Océanographie Physique" has undertaken, as part of its normal activity, to publish lists of monthly and annual mean heights of sea-level observed at stations which are representative of world wide conditions, it is recommended that the publication of the sea-level tables in the *Bulletin Hydrographique* be discontinued from the year 1937, and that the sea-level material collected for publication be transmitted to the General Secretary of the "Association Internationale d'Océanographie Physique" for inclusion in the publications of that body.

b) It was recommended that forms for entering hydrographical observations should be prepared and sent out to contributors of hydrographical material for the Bulletin. With the first dispatch of such forms, separates of the report from the Sub-Committee for nomenclature and units to be used in the publications of the Council should be supplied. (This volume, part III, 1.)

c) It was recommended that the sections on meteorology in the Bulletin should be discontinued.

d) It was recommended that current measurements and mean values of observed currents — especially those from lightships — should not be incorporated in the Bulletin but that they should be published with some discussion in the Administrative Report. Dr. CARRUTHERS was nominated as a reporter for the purpose.

2) The chemical nomenclature and units proposed by the relevant Sub-Committee (JACOBSEN, K. BUCH, B. SCHULZ and H. WATTENBERG) — and printed as Appendix No. 1 in part III of the present volume — were recommended for use in the publications of the Council.

3) It is recommended that Dr. JACOBSEN represent the Council at the meeting of the "Association d'Océanographie Physique" at Washington in 1939 without expense to the Council.

III. Pro Memoria.

1. Investigations of the Gulf Stream.

The changes of temperature in the Gulf Stream from year to year are determining factors for the condition of the North Atlantic and adjacent seas and for the weather conditions in North Europe. One of the most important tasks of sea exploration, therefore, appears to me to be that of watching and studying these changes from season to season and from year to year.

[1]) In the questionnaire is asked for information on several topics of physical oceanography "with a view to meteorology, navigation and marine biology".

[2]) See amendments; Consultative Ctee., page 25, 3, b.

[1]) See Consultative Ctee., page 25, 3, a.

The changes of temperature in the Gulf Stream from year to year are variable and can amount to several degrees. These great changes should not be confused with the rapid and small changes of temperature amounting to a few tenths of degrees, which occur in the Gulf Stream owing to its heterogeneity, induced by the periodic absorption into the Gulf Stream of water of another temperature and salinity from the surrounding seas. My studies of these occurrences, spread over a period of ten years, have shown that the great changes in temperature from season to season and year to year are unaffected by these small variations and are very little disturbed by them.

Fig. 1. Schematic sketch of annual and casual changes of temperature in the Gulf Stream.

On the basis of this volume and variations of the Gulf Stream might be investigated according to a plan as suggested in the following:

At a number of selected hydrographic stations the usual hydrographic observations are carried out of the temperature, salinity, nitrates, phosphates, etc., including light measurements, necessary for production in the sea. These should be carried out at the same season and same place year after year, so that from the observations there can be read direct both the annual variation in the condition of the Gulf Stream and the change in the Stream from year to year at these selected stations.

The observations should be carried out when the water of the Gulf Stream is warmest and when it is coldest, that is to say, in August and February, and when the warming and cooling stages are at their height, namely, in May and November. In August and February the summer and winter temperatures can be gauged, in May and November we can ascertain whether the Spring and Autumn in the Gulf Stream are early or late.

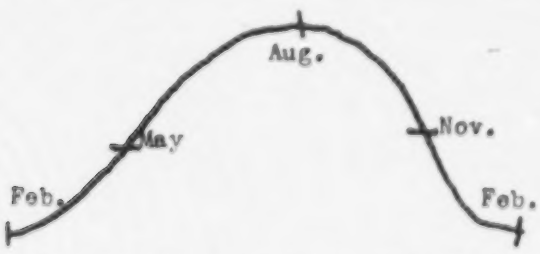


Fig. 2. Temperature Curve and Observation Months.

The hydrographic stations might be situated quite far from each other. Five or six stations are sufficient for each section of the Gulf Stream.

The undoubtedly most important section across the Gulf Stream is the section along the Shetland-Iceland Bank, on both sides of the Faroe Islands. In this strip of the North Atlantic can be studied both the north-going warm branch of the Gulf Stream on the surface and its returning cold branch on the bottom of the sea. Here measurements of the current should also be made for calculation of the volume of water flowing in both these branches.

The most important section south of the Shetland-Iceland Bank runs from Chesapeake Bay to Bermuda where the Gulf Stream first properly becomes an independent current. Here the Woods Hole Institution already carries out the observations proposed in this P. M.

The most important section north of the Shetland-Iceland Bank runs from the northwest corner of Norway, from Andenes to the N. W. Here the Gulf Stream is very concentrated and presses hard against the Norwegian Coast. A couple of hydrographic stations off the coast, if the weather does not permit of a complete section, would here be of particular value.

As the Americans already carry out the proposed observations in the most southerly of the three standard sections it is thus only in the two remaining standard sections that observations need to be organised by the International Council for the Exploration of the Sea.

The observations in the three standard sections could, and should, be supplemented by others which are easy to carry out and which in a high degree would enhance the value of the standard observations.

Among these are first and foremost observations of the surface water temperature each week at the Faroe Islands. In the vicinity of these islands there is no coast water from rivers etc., covering the Gulf Stream water which therefore subsequently rises to the surface where it is strongly stirred by the tidal currents and thus gives a true picture of the temperature of the Gulf Stream. These easily effected surface water observations there furnish a continuous picture of the temperature variation of the Gulf Stream water throughout the whole of the year in this important part of the North Atlantic.

On the coast of Norway the water of the Gulf Stream is overlaid with coast water but under the coast water the fjords without thresholds are filled with Gulf Stream water which is constantly pumped in and out of the fjords by the tidal water and therefore quite reliably indicates the temperature of the Gulf Stream off the coast. Here, with deep water thermometers, or even better self-registering electric distance thermometers it should be possible to study

the annual variation in the temperature of the Gulf Stream water.

At Spitsbergen the same system of registering the temperature of the Gulf Stream water can be adapted in some of the big fjords in the neighbourhood of the coal mines. But here a hydrographic cross-section should also be made each summer in August over the Gulf Stream immediately before it goes under the Polar ice. At other times of the year this is impossible owing to ice conditions.

The enormous area of warm water of the Gulf Stream, its dominating influence on all occurrences in the sea and in the atmosphere of the surrounding continents, its great variations from year to year, which are reflected in these occurrences and cause the years to differ from each other both as regards fishing and weather conditions, render it highly desirable to commence and maintain a permanent investigation of the Gulf Stream and its changes, along the lines indicated above.

J. W. Sandström

2. Suggested Investigations of the Production of Phytoplankton by International Cooperation.

The production of phytoplankton is dependent on the occurrence of: 1) dissolved nutrient substances, first and foremost of nitrates and phosphates and of 2) light.

1. The means of subsistence are consumed in the surface layers, as far down as the lighting is sufficient, and on account of this consumption the production in a water mass must decline until the quantities of nutrient substances can be renewed, either by vertical circulation or by decomposition of those quantities which are bound in the bodies of the plankton animals.

In the winter, when the surface layers are cooled, the vertical circulation is always sufficient to conduct larger or smaller quantities of nutrients up to the illuminated zone. During the spring, therefore, we shall always find everywhere the most abundant period of production.

The time at which this production commences differs in the different marine areas.

2. This period will first and foremost be determined by the illumination. Under otherwise equal conditions of light growth will first commence in the areas in which the water layers are first stabilised, because the specific gravity of the surface water is reduced by warming or by the addition of surface layers having a less saline content, as along the coasts of Scandinavia. In the Skagerak the development commences in February, on the west-coast of Norway in March.

As long as a vertical movement of the water masses is in progress the plankton algae will participate in the movement, so that each cell only receives a fraction of the light which reaches the surface layers. If the surface illumination is only just sufficient to enable the assimilation to prevail over the respiration the vertical circulation will prevent the development of an abundant phytoplankton. In the summer, when the volume of light is sufficient in our latitudes down to 30—40 metres, or even deeper in the open sea, the vertical circulation can still check the development if the movement extends essentially deeper than to those depths which mark the point of compensation between assimilation and respiration.

In the Northern Atlantic the development of the phytoplankton commences in May, in other words a month later than in the Norwegian coast-waters. It is probable that this delay is due, first and foremost, to the circumstance that the water masses first become sufficiently stabilised at this point of time.

On the other hand it is precisely as a result of the stabilisation that the nutrient substances are rapidly consumed whereby the productive period is thus of short duration.

Along the coasts of northern Europe and North America we are now aware of the annual periodicity in the development in its main features. In the oceanic parts of the North Atlantic there is still only a limited number of observations available. On the basis of the material available Steemann Nielsen[1]) has sketched (l. c. p. 72) the probable course of the annual development in the different sectors of the area. Across the ridge between Iceland Faroe Islands — Shetlands the available material seems to show that a considerable production takes place from May onward throughout the whole of the summer. In the Gulf Stream area to the north and to the south of the ridge a high production takes place in May and June, while the phytoplankton is poorer during the rest of the year.

This area in particular is specially interesting for determining the productivity of the whole of the northern Atlantic. It would be of the greatest interest if a thorough investigation could be carried out of the plankton production in connexion with the occurrence of oxygen, nitrates and phosphates, preferably also with light measurements throughout one season from and including April up to and including September. I would propose the following periods:

1. About the middle of April
2. About the middle of May
3. About the 1st July
4. During the latter half of August

I shall have the honour to submit verbally during the Council Meeting at Copenhagen in May a more detailed version of this proposal.

H. H. Gran.

[1]) E. Steemann Nielsen: The production of phytoplankton. I. at the Faroe Isles, Iceland, East-Greenland and in the waters around. Medd. fra Komm. f. Danmarks Fiskeri- og Havundersøg., Ser. Plankton. Bd. III. Nr. 1. Copenhagen 1935.

3. Proposal by the Chairman of the Consultative Committee.

The International Council, in its Bulletins and other publications, has issued surveys of the collective results of the hydrographic investigations and plankton investigations carried out during the quarterly cruises in previous years, and a survey is now being prepared by Mr. SANDSTRÖM, Directeur de Bureau, of the hydrographic material collected by the International cruises through a long series of years. By special hydrographical and biological sub-committees standardized methods have been developed for the quantitative determination of nutrient compounds of the sea water, for the measurement of the direction and speed of currents, of light determination and the quantitative distribution of the plankton of the sea. In the hope that the time may now have arrived for more rational planning for the future on the basis of this survey I have conferred with Mr. SANDSTRÖM and the Chairman of the Plankton Committee, Professor H. H. GRAN, and with their support I venture to urge the Consultative Committee to discuss the question of such a plan for the future.

I assume that this can best be done by a committee specially appointed for the purpose which can work out the details of the plan and submit a proposal to next year's Council Meeting, but even at this stage I desire to indicate the main tasks which, as a result of the conference mentioned above, I must regard as the most important.

Plan of Hydrographic-Biological Investigations.

I. The question of alternation in ocean currents and a characterisation of their volume from the one year to the other.

(a) "The Gulf Stream" as a measure of the influence of the Atlantic Ocean on North European waters. According to a P. M. by Mr. SANDSTRÖM (see above) he considers as necessary for the initial orientation of the question a cross-section of the waters Shetland–Iceland four times a year, from Spitsbergen westwards to the ice at the beginning and end of the navigable season. It is of great importance to endeavour to secure cooperation with the North American investigations of the Gulf Stream as previously carried out by the Woods Hole Oceanographic Institution, also the cooperation of the Bermuda Biological Station might be secured in as much as this institution is cooperating with the Woods Hole Institution on the questions of the Gulf Stream investigations further south.

(b) It is considered desirable that the investigations of the English Channel, the North Sea and Skagerak which have previously been undertaken should be continued in cooperation with this.

II. (a) An investigation of the annual period in the production of the sea under the influence of the factors now known (the nutrient substances and the light) should be carried out for one individual year, special emphasis being laid on the above-mentioned area Shetland–Iceland. Subsequently, the results thus obtained will be capable of supplementation in connexion with the hydrographic investigations, which are carried out four times a year, with the object in view of studying the correlation of the annual alternations in the marine currents and alternations from year to year in the production of the sea and eventually in the conditions for the numerical strength of the year-classes of important food fishes.

(b) In conjunction with the investigations in the Atlantic Ocean similar investigations should be carried out in selected coastal waters of a specially interesting character.

28. April 1928.

JOHAN HJORT.

Sub-Committee on Combined Hydrographical and Biological Investigations.

Members: Prof. M. KNUDSEN, Prof. H. H. GRAN, Dr. le Ed. DANOIS, Prof. R. SCHULZ, and Dr. STANLEY KEMPS.

The Committe met on May 26th to consider work to be done in the near future; it was decided to have a meeting in the autumn after receipt of replies to a circular letter issued.

Appendix 3. Text of presentation by the president of ICES at the 1950 Statutory Meeting stressing the critical role of physical oceanography in resolving fisheries problems

APPENDIX B

Co-operation between Biologists and Hydrographers

By

K. A. Andersson

In a letter to me, the Chairman of the Consultative Committee, Dr. Clark, has told me that he intends to take up the question of the closer relationship between biologists and hydrographers for discussion at the next meeting of his Committee.

As I raised this question at the Bureau Meeting in May 1950, I feel I should say a few words.

In spite of the extensive international biological and hydrographical investigations already made, and of the very important results obtained, many important problems concerning the influence of the environment on the animal life in the sea are still awaiting solution. Let me take some examples from the herring, which I have studied to some extent. We do not know whether, and if so to what degree, the hydrographical conditions are responsible for the occurrence of different herring populations with, for instance, varying numbers of vertebrae. We do not know to what extent the environment is the cause of the varying abundance of year-classes, and we do not know whether it is changes in the sea currents or in the general hydrographical conditions that have occasioned the great fluctuations in the herring fishery off the west coast of Sweden. These are but a few examples from the herring. I believe that similar instances can be cited in the case of other fish.

Immediately after the Council Meeting in October 1945, there was a meeting in Charlottenlund with herring experts particularly interested in the herring fisheries of the Transition Area.

At this meeting the herring problems of the said area were thoroughly discussed, special stress being laid upon the desirability of examining the part played by the hydrographical conditions in causing the great fluctuations in the herring fisheries in the Skagerak and the Kattegat.

The eleven recommendations made at this meeting included one to the following effect.

"Hydrographical investigations should be undertaken on the spawning grounds of the herring at the time of the spawning season. If possible, such investigations should be carried out in the form of continuous observations during the spawning period."

This recommendation was accepted with a view to ascertaining the influence which the hydrographical conditions especially temperature and salinity exert upon the abundance of year-classes. Moreover, such hydrographical work on the spawning grounds should also prove whether the different characters of the various so-called herring races could be a result of the different environments.

At the Council Meeting in 1945 a Sub-Committee was also formed to discuss the organization of combined hydrographical-biological investigations.

At its first meeting in August, 1946, this Sub-Committee suggested *inter alia* that the problem of the influence of hydrographical factors upon the biometrical characters used in race work should be studied by means of hydrographical investigations on the spawning grounds of food fishes, especially the herring.

Subsequently, in May and September, a number of sections were made across the North Sea, the Skagerak and the Faroe-Shetland Channel.

At the meeting in Edinburgh last year of the Hydrographical Committee it was agreed – at the suggestion of the Sub-Committee – that the results obtained should be worked up into a comprehensive report before further action was taken.

I am sure that very valuable results – from the biological point of view also – will emerge from this hydrographical work.

But I feel nevertheless that a still closer liaison between hydrography and biology is essential. For I am not convinced that the hydrographical results available can supply answers to all the questions that may be asked by biologists concerning the environment. In order to judge correctly the influence exerted by the physical and chemical conditions in the sea upon the animal life, it is frequently necessary for the hydrographical conditions to be studied in a certain defined area during a fixed period of time when something of particular biological importance is taking place in that area. For instance, if you wish to know the influence that may be exerted by the hydrographical conditions upon the embryonic development of the herring, it is necessary to undertake hydrographical investigations on the spawning grounds at the time when that development is taking place.

It is of course a well-known fact that we have a spring spawning herring off the east coast of Scotland whose vertebral number is about 57, while the Norwegian spring spawning herring which spawns

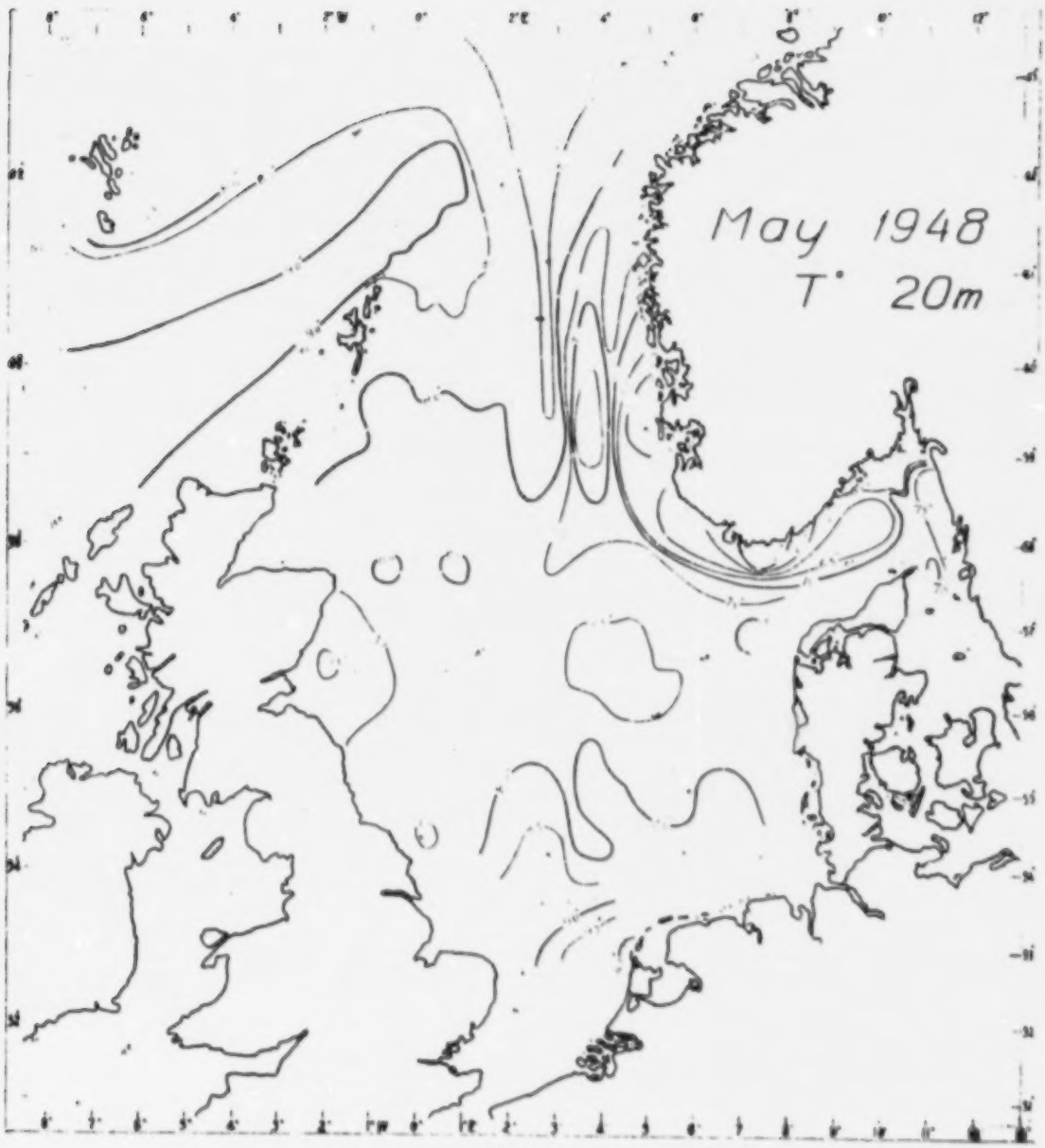


Chart 1. Prepared by J. Eggvin

off the south-west coast of Norway has about 57.40 vertebrae. What is the cause of this difference in the number of vertebrae? Is it varying hydrographical conditions in the two spawning areas?

At my request Dr. Eggvin has been kind enough to send me extremely interesting information about the temperature of the water at 25 and 50 m. at the west coast of Norway for February and March 1912–1919 (Table 1). This shows that the variations are very great from year to year. He has also sent me two temperature charts for May 1948 at 20 m. and 50 m. in the northernmost North Sea (Charts 1 and 2).

Chart 2. Prepared by J. Eggvin

Table 1. Monthly Average Temperatures. 59°15.2' N. - 4 46.5' E. (Utsira).

	February.								March.								
Year	1942	43	44	45	46	47	48	49	Year	1942	43	44	45	46	47	48	49
5 m		6.0	6.3	4.6	5.4	4.5	4.6	6.7	25 m	4.3	5.4	5.4	5.4	4.6	3.6	4.4	5.6
30 m		6.2	6.4	5.1	6.6	4.8	5.3	6.8	50 m.	2.1	5.5	6.0	5.4	4.8	4.2	5.2	5.7

These show that the temperature was higher off the Shetland Islands and the north of Scotland than on the coast of Norway opposite. But of course it tells us practically nothing about conditions during the spawning period in March and April. A similar temperature chart for March and April would in my opinion be very valuable. That is why I consider that investigations should be made in the spawning area during the period in which the eggs develop.

I have wished to draw attention to these well-known facts merely as an instance of the desirability, in my opinion, of closer co-operation between biologists and hydrographers.

The Chairman of the Consultative Committee has put this question on the agenda and I have heard from Dr. CLARK that some of the Area Chairmen have already considered this problem.

It is my wish that this question should come up for discussion in the different committees and that they should be able to put forward definite problems which they wish to have solved by means of hydrographical investigations. The more these problems can each be defined and fixed the better. For instance, if you want to have the hydrographical conditions in a spawning area investigated, then it is essential for the biologists to give the exact position of this area and the time during which it is desired to carry out the hydrographical investigations.

Now I am sure that I have been too long, but I have come to the conclusion that this question is of paramount importance and extremely likely to promote the interests and activity of the Council.

Now I only hope that the hydrographers will not think that we biologists are asking too much of them.

Appendix 4. Recommendations of the Special Scientific Meeting on Fisheries Hydrography held in Amsterdam, 1951

Southern North Sea (in conjunction with Netherlands and British workers).

After some discussion the following resolutions were transmitted to the Consultative Committee and were ultimately approved by the Council.

The sincere appreciation of the meeting was expressed by the Chairman to Dr. BULL and the other contributors for their stimulating papers, this appreciation being subsequently endorsed by the Council in General Meeting.

Recommendations as amended by the Consultative Committee.

1) As the proceedings of this meeting have shown that a combination of biological, hydrographical, meteorological, physiological or statistical researches has furthered our knowledge of biological productivity, of the habits of the fish stocks, and also the fisheries themselves, it is recommended that researches along these lines should be continued.

2) It is recommended that committees should state as definitely as possible what problems they wish the hydrographers to attack and solve.

3) It is recommended that compendious studies of the normal behaviour of our major food fishes should be carried out either by direct observations or by laboratory experiments.

4) It is recommended that efforts should be made to encourage the writing of monographs describing the hydrographic conditions in the seas in which fishery research workers are interested.

5) It is recommended that as a direct means of showing the dependence of the fish stocks on hydrographic conditions, and as a direct help to the fisheries, experimental fishing on a commercial scale and other forms of assessment should be carried out simultaneously with hydrographic observations.

6) It is recommended that the immediate aims of the Plankton Committee should include (i) studies of the basic conditions of productivity in the sea, and (ii) an attempt, by observations over a series of years, to correlate the number of survivors of a year-class of fish with the presence or absence of any one or more types of plankton organisms, both predatory and food-producing, during the early planktonic life of the fish.

7) It is recommended that the contributions to this meeting be published by the Council as a special report. Contributions that are or will be published elsewhere should only be abstracted in the report.

8) It is recommended that the results for cod near Bear Island and for herring in the open Norwegian Sea be brought to the attention of the fishermen of all countries.

A. For cod fishing near Bear Island.

(i) That on grounds west of Bear Island, in early summer and again in autumn, atlantic type water touching the bank can give good trawl catches, with bottom temperature near $3^3/_4$° C.

(ii) That west of Longitude 20° E. a bottom temperature of less than $1^3/_4$° C. is generally unfavourable, and so may cause concentrations of cod near its boundary.

B. For herring in the Norwegian Sea.

During the last 4 years (1948—1951) herring shoals have been observed in extensive areas over the deep water north and north-east of the Faroe Isles in May-June.

Later in the summer the shoals seem to concentrate in the border region of the East Icelandic Arctic current between 66° N. Lat. and Jan Mayen. In the two recent summers the Norwegian investigations have shown that the herring shoals are also numerous from Jan Mayen north-estwards along the border between the atlantic and the arctic water, temperature approximately 6—8° C. in the open sea.

Last summer (1951) herring drifters made good catches 80—100 n.m. east of Langanes, Iceland, and also in the Jan Mayen area.

Appendix 5. Extracts from the recommendations arising from the ICNAF Environmental Symposium held in Rome, 1964

APPENDIX VI
REPORT OF THE SUBCOMMITTEE ON ENVIRONMENTAL STUDIES

Chairman: Dr. C.E. Lucas

(a) On Monitoring (para. 3) the Subcommittee

recommends (33)

that the observations of environmental factors at coastal stations and offshore points, including weather ships and moored buoys, and making the fullest use of automatic recording apparatus, be continued and encouraged with special reference to temperature and current measurements: with the objective, first, of monitoring the hydrographic conditions and, second, of finding ways and means for predicting long-term trends which may be of significance for the fisheries.

(b) On other environmental factors (para. 4) the Subcommittee

recommends (34)

(i) that the attention of hydrographers be drawn to the value in fisheries investigations of information concerning a range of environmental factors additional to the conventional ones, particularly direct current measurements and measurements of the intensity and quality of submarine light and their rates of change.

(ii) that, as the environment is naturally a complex of factors, and the real effects of any one factor may not be found by studying it alone, attention must also be paid to the inter-relationship of factors.

Environmental Subcommittee

Annex 1. Informal Report on the Environmental Symposium

1. Humans are seldom left unaware for long of the effects of the ever changing environment, but in many ways cold-blooded animals are even more immediately subject to these variations, perhaps particularly those living in intimate contact with the marine environment. Situated as they are, along a relatively narrow Continental Shelf extending over some 30° of latitude, the fisheries of the ICNAF area may be regarded as particularly exposed to changes in their aquatic environment, ranging from water movements that may carry fish eggs and larvae and their food off the Shelf to major climatic changes in the North which may permit or make impossible the continued existence of stocks of commercial fish. ICNAF has made considerable progress in assessing the stocks of fish at present available, and is beginning to tackle the problems of the effects of fishing on them, but it was the recognition that such assessments are always subject to environmental qualifications that resulted in the environmental programme of 1961. This comprised three main parts, (a) the general programme from which results are now emerging each year, (b) the environmental survey on which Mr. Lee will be reporting and (c) the Environmental Symposium which was held this year in Rome.

2. The circulated reports of the Conveners, and introduction by the Chairman, provide a general account of what was a well attended and valuable series of meetings. In addition to bringing together masses of data hitherto unavailable, it provided opportunities for scientists to meet and exchange ideas, and indeed confront each other with different interpretations of the available data. Two important points which were immediately evident were (a), despite their bulk, the relatively limited nature of the environmental data being collected (principally concerning temperatures) and, to some extent consequentially (b) the tendency to produce over-simplified and possibly at times fallacious associations between, say, temperature variations and variations in fish numbers etc.

3. For all that the need was recognised and strongly urged for an increase in the monitoring of both temperature and salinity data, for different regions over the whole North Atlantic, so as to understand better how these may be linked and so as to have even better data for association with trends in the fisheries. At least two conveners advised us to consider passing resolutions on this subject, and several drew attention to the importance in fishery studies (and indeed to the

fisheries) of meteorological data, because of the significance for the aquatic environment of exchanges across the air/water interface. In deputising for Dr. Marty, Mr. Parrish in his report also touches on such matters when drawing attention to the importance for fisheries and fishermen of environmental factors ranging from weather to the nature of the sea bed.

4. It was repeatedly stressed, however, that insufficient environmental factors are being investigated in detail. Those being neglected include possibly some of whose significance we are as yet unaware, but among those with which we are familiar, nutrients, the planktonic and other food organisms, the strength and direction of ocean currents and the intensity and quality of submarine light are evidently of great significance. It was also stressed that the environment is naturally a complex of factors, so that the real effect of any one may not necessarily be found by studying it alone; consideration should be given to the effects of the inter-relationships of factors and, as laboratory work in this and other fields has shown, to the rates of change of environmental factors and possible threshold values that may serve as triggers to influence responsive elements, neural or hormonal, in the internal environment of the fish.

5. It is reflections such as these that convinced most if not all of those present of the urgent need for studies, in integrated detail, of both the environment and of the fish (and their fellows in the marine community) themselves. In order to understand the environmental picture it is necessary not only to understand it in detail, but to understand in corresponding detail the reactions of the fish to different aspects of the environment (including fishing gear), and the internal processes governing them. This conclusion points strongly to the need for much more experimental work, not only in the laboratory but also in small scale "semi natural" environmental situations, such as those envisaged by ICES in the experimental herring programme it is at present considering.

6. In one fishery or another there have already been a number of investigations of the well known fluctuations in the abundance of year classes, and their relationships to the even greater fluctuations in the abundance of eggs, larvae and young fish. But great difficulties have been met in assessing such fluctuations with the requisite accuracy for comparison with commercial data, and many speakers stressed the need for greater facilities and for more careful planning of such investigations. It is necessary also to understand more than we do at present about spawning processes and the factors influencing them. There is a dearth of information about young fish in the first year or two of their lives - a stage of life history which is very difficult to sample but which must be studied if we are to understand the causes of fluctuations in the strengths of year classes.

7. It was considerations of the environmental aspects of such fluctuations that led to the planning of the NORWESTLANT survey. While this was remarkably successful in many respects, perhaps its principal feature was the remarkably small numbers of larval fish resulting from relatively good spawnings. Not surprisingly, also, experience on this first large scale cooperation under ICNAF auspices has suggested ways in which such a programme might be improved. In

particular, there was a general feeling among those attending the Symposium that the value of the results would be greatly increased if the survey could be repeated, if possible even more intensively, based on the analyses of the results in 1963 and the experience gained in this first large scale cooperation under ICNAF auspices.

8. There is no need here to stress the rapidly developing interest in the offshore stocks of herring in the ICNAF area, and an additional section of the Symposium was planned to bring together information already available. Perhaps the chief conclusion was that much more work is needed in the important task of identifying the different stocks and components concerned in these important herring fisheries.

9. Perhaps the last of the important points arising, now being experienced fully in all aspects of the Commission's work, is the essential part to be played by cooperation between laboratories, between countries and between workers in different disciplines, if real success is to be achieved. Not only is cooperation needed, however, but in many instances greater research facilities will be essential if results which are applicable, and on which complete reliance can be based, are to be obtained. Perhaps a moment's reflection on the tremendous size of the oceans, and the tremendous distances over which fish stocks, and individual fish range, will show that this is not unreasonable.

C. E. Lucas
21st May, 1964

Appendix 6. Oceanographic monitoring requirements of the Fisheries Research Board of Canada in the Atlantic and Arctic Regions

INTRODUCTION

At the Atlantic Fisheries Oceanography Meeting (DM & TS and FRB personnel) held at the Bedford Institute of Oceanography on February 17-18, 1964, the need for environmental information by fisheries biologists was discussed at length. Although temperature is considered to be of prime importance for many marine organisms, there are several other environmental factors that exert an influence on the various fisheries. In many instances the relationships are not understood. Where this is the case, research studies are necessary in order to obtain a basic understanding of the relationship between the organisms and their environment. Ultimately, understanding of the basic cause - effect relationship should allow monitoring of the oceanographic environment in such a manner that it will permit forecasting of fisheries conditions.

It is generally agreed that there is a strong need to obtain quantitative figures that interrelate the concentration, distribution, and abundance of fish to the environmental factors. This is required both for the biological and non-biological parameters. In most instances, however, there is little doubt that if quantitative relationships are to be found, a major increase in monitoring effort will be required in the northwest Atlantic.

It was agreed that DM & TS would accept the responsibility for monitoring oceanographic conditions. The present monitoring carried out by FRB will be gradually taken over by DM & TS and expanded when personnel become available. It was further agreed that FRB would place their specific requirements before DM & TS. Priorities would be specified.

Subsequently, the Biological Stations at St. Andrews, St. John's, and Montreal reviewed the present monitoring work and considered what their future needs were, based on their present understanding of the fisheries. These have been incorporated in this report.

GENERAL MONITORING REQUIREMENTS

The basic monitoring requirements, expressed in general terms, are best summarized by the ECWG Panel on Fisheries Requirements in Oceanography:

1) Monitoring seasonal and annual changes in surface and bottom currents, temperature and salinity stratification, and light conditions in selected areas over the continental shelf. Biologists are already making good use of monitoring changes of temperature conditions and believe that even greater success should result from monitoring seasonal and annual changes in surface and bottom currents and the study of effects of this water transport on fish and fisheries.

2) Monitoring seasonal and annual changes in indicator organisms and fish eggs and larvae. This involves establishment of personnel and facilities, preferably closely associated with the programs of studying ecological conditions.

PRESENT MONITORING

The present monitoring carried out by FRB is given in the accompanying Table. The efforts of other Canadian agencies are also tabulated but the list may not be complete.

It should be noted that the items listed are almost exlusively limited to the physical environmental factors. Biological monitoring is being carried out in the fisheries by studying landings, effort, size composition, discards, dominant year clases, distribution of adults, juveniles, and in some cases, larvae.

ANALYZING AND REPORTING

A) Water Properties:-

Monitoring sponsored by the St. Andrews Station is reported to that station on a monthly basis. Observations are compiled on a monthly basis and analysed and reported annually. If large anomalies or unusual results are detected, interested investigations at the Station are advised. Surface temperatures observed at St. Andrews and Entry Island are reported daily to the Meteorological Branch.

The monitoring carried out by the St. John's Station is analyzed by that station, used internally, and reported annually.

The Atlantic Oceanographic Group has the responsibility for seeing that the Halifax and Cabot Strait sections are run. Occupation of the section is carried out by one of the ECWG agencies. The analyses are done by either St. Andrew or AOG and are reported annually. It is a Canadian commitment to ICNAF.

B) Circulation:-

Releases of drift bottles and sea bed drifters are reported in St. Andrews on a monthly basis. Recoveries are continuously compiled in 5 stages and are analyzed and reported annually. Any unusual results detected during the compilation are reported to interested investigations.

In general all compiled monitoring data are being used by fisheries scientists as soon as they are available. Comparison of monitored information with environmental aspects of fisheries research (survey data) is constantly reviewed for internal use.

FURTHER MONITORING REQUIREMENTS

The monitoring presently being carried out by FRB should be continued and given high priority by DM & TS. In addition, the monitoring program should be expanded in most areas.

1) In the Gulf of St. Lawrence there is need to monitor oceanographic conditions that are of concern to several investigations: groundfish, salmon, herring, etc. Specifically there is a need to monitor conditions in the approach areas of the Miramichi River and along the southern edges of the Laurentian Channel, across the Strait of Belle Isle, and across the Esquiman Channel.

To meet present needs that are of specific value the following sections should be monitored quarterly:-

a) Cabot Strait
b) Miramichi River to Laurentian Channel
c) Bay of Islands to Cape Whittle
d) Belle Isle Strait

2) Gullies:-

Considering the increased emphasis of groundfish work during the last few years in a series of gullies (indentations in the Shelf) monitoring of oceanographic conditions in such areas has a high priority. There are four gullies where biological work is being carried out: Gaspe coast, Bay of Chaleur, Northwest Cape Breton, Southeast Cape Breton and Sable Island Gully (see Diagram). It is suggested that the first three be monitored in this way: one monitoring station providing temperature and salinity at standard depths at each of the first three gullies, visited twice a month for a period of a year to 15 months, before a longitudinal section in each of the three gullies is established on a quarterly basis.

3) Section Shelf and Georges Bank:-

The area south of Nova Scotia is of special and growing interest. A section from Cape Sable across Browns Bank run quarterly would be of special value to research on swordfish, herring and groundfish. If it proved practical to extend this section as far as Georges Bank, it would give results of great interest to scallop investigations also.

4) Newfoundland-Labrador Areas:-

a) Two additional sections off the Labrador Coast should be occupied annually in the last part of July or early August. An effort should be made when running these and other sections in Newfoundland and Labrador areas to occupy the same section at the same time each year (within, say, one week).

b) For purposes of larval drift and adult fish migrations, it is desirable to have information on current patterns over the continental shelf and slope. The mean monthly temperature distribution is also considered important for fish larval distribution and survival. The most important period to have this information is from March to August.

5) Arctic Regions·-

There are regions within the Canadian arctic where periodic monitoring (annual or more frequent) of plankton would serve to reveal long-term characteristics or trends in the biological composition of the sampled waters and hence in associated environmental features. In the east, accessible areas (by ship) and in a sense key areas, are the east end of Hudson Strait, the west end of Amundsen Gulf and of M'Clure Strait. Sampling at close to the same time (or times) of each year would be essential, and a fairly simply carried out series of collections at a few stations in each region would supply the data required. The basis of assessment would be the quantitative occurrence of indicator organisms, associated ecologically with Arctic, Atlantic and other water masses.

Anticipated whale investigations in Amundsen Gulf will require periodic assessment of physical features and plankton distribution. A periodic monitoring program would serve to elucidate the features of the environment including food supply of the whales as well as to provide sight records of whale occurence.

6) Plankton, Eggs, and Larval monitoring in Canadian Atlantic:-

Although fisheries biologists are not in a position at present to make detailed requests for routine plankton studies, there are certain general points that should be brought out.

In order to arrive at a satisfactory understanding of the biology of the arctic species of both zooplankton and phytoplankton certain data from non-arctic locations are desirable. Most of the major plankton species of arctic Canada are among the more important species of the waters off southeastern Canada. This indicates not only a continuity of distribution, but also a continuity of response to environmental conditions, from the high arctic environment to the essentially subarctic to boreal environment of the Canadian Atlantic provinces. There is a need at the present time not only for detailed distribution studies on these species (along with others) in the southeastern Canadian region, but also for studies on the biology of the species.

If sufficient monitoring of the physical environment can be inaugurated then FRB would be interested in cooperating in collection and working up of plankton, eggs, and larval data in the Canadian Atlantic region. This information would be valuable to the Atlantic fisheries, and at the same time would serve to gain fundamental biological knowledge of phytoplankton and zooplankton that would be applicable to both the Atlantic and Arctic regions.

7) Whales and large pelagic fishes:-

Only limited information is available concerning the distribution and abundance of whales and large pelagics in the N.W. Atlantic. Preliminary work carried out south of Nova Scotia has indicated possible significance in the association between occurrence of zooplankton and whales. Additional macroplankton and physical oceanographic monitoring in the region could possibly be combined with offshore tuna studies. More specific monitoring requests in this respect will be documented at a later date.

SUMMARY

The oceanographic monitoring presently carried out by FRB is considered minimal. In future monitoring, therefore, this should be considered as having top priority. No part of it should be dropped unless it can be shown that the same information can be provided in other ways, that yield more information, or is more economical to operate.

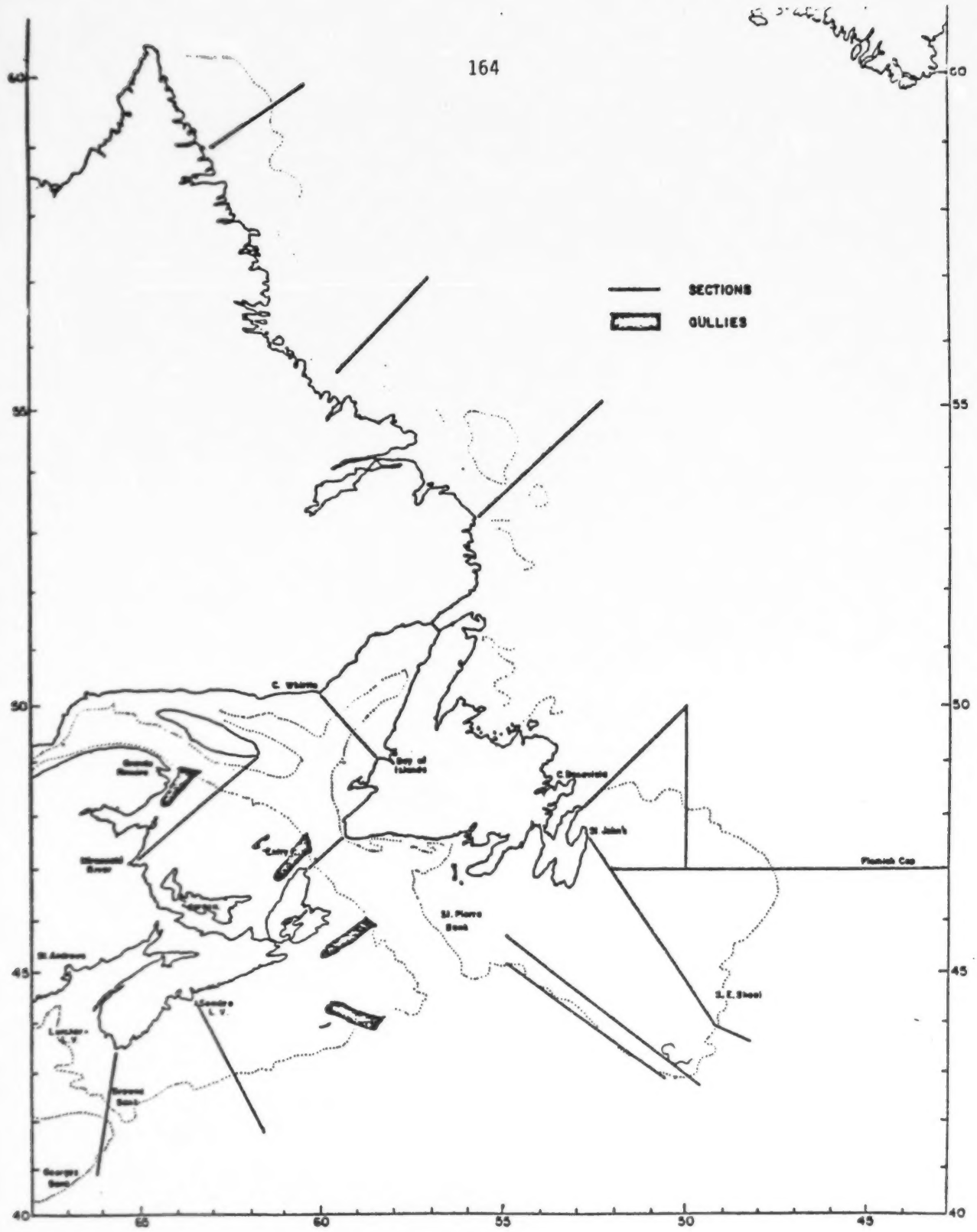
Expansion of physical oceanographic monitoring is recommended. At the present time, first priority should be given to the Gulf of St. Lawrence and the Gullies. As soon as capabilities permit, increased monitoring (temperature and salinity) should be carried out on the Scotian Shelf and Georges Banks, and off the Labrador Coast.

For the purposes of plankton, eggs and larval drift, and adult fish migrations, it is desirable to have information on the mean monthly surface and bottom current and temperature patterns over the continental shelf and slope. The most important period to have surface information is from March to August. Any extension in a field program to acquire this information should be accompanied by plankton collections and studies. More specific monitoring requests in this respect will be documented at a later date.

In general all compiled monitoring data are being used by fisheries scientists as soon as they are available. It is desirable that analysis similar to those already carried out by FRB be provided and extended when DM & TS take over the monitoring service.

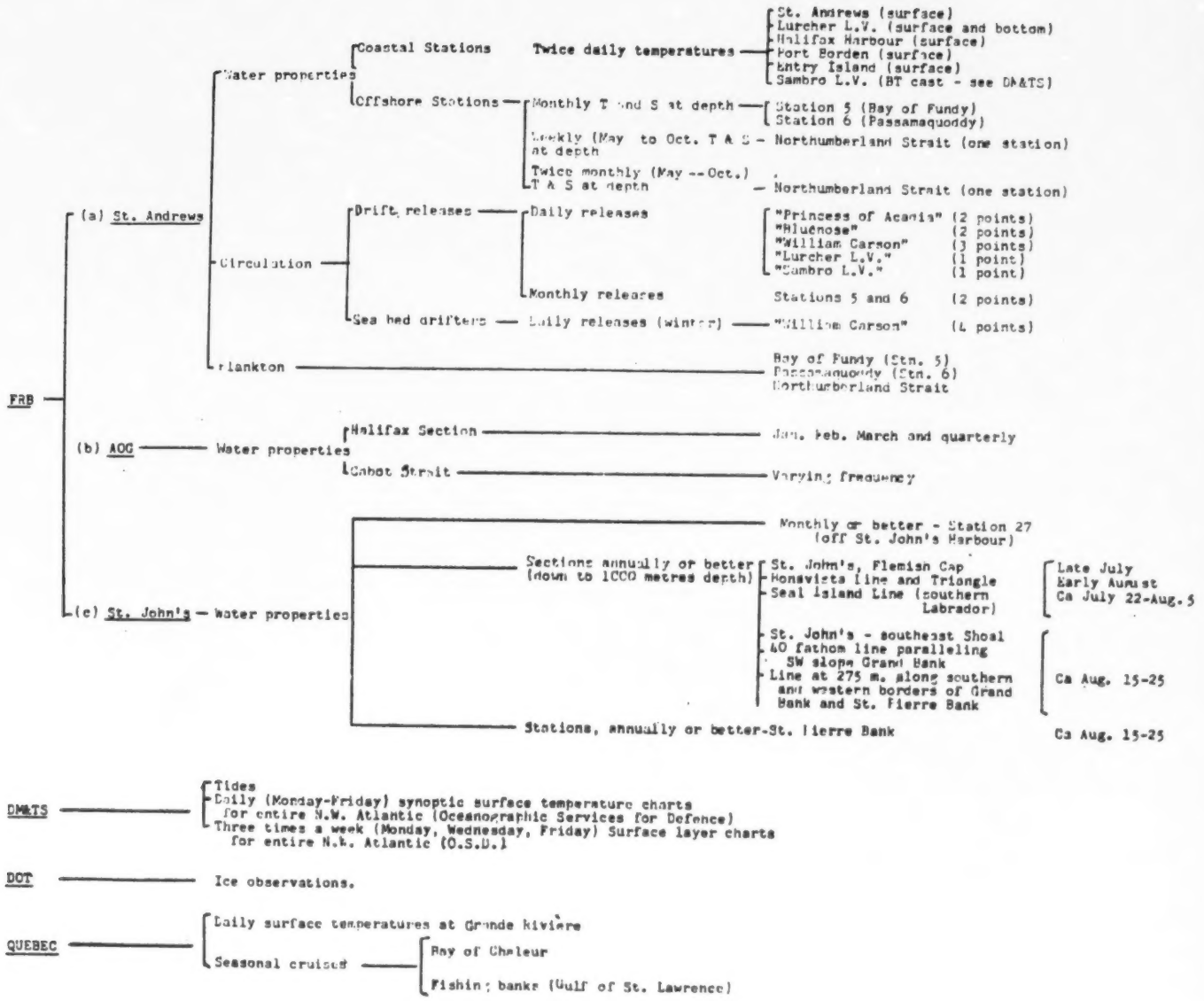
When all the monitoring services requested above have been provided there will still be major gaps in knowledge of the interrelationships between the environment and fisheries. It is clear, therefore, the location, frequency, and type of monitoring will be altered from time to time, according to the results obtained form specific research projects.

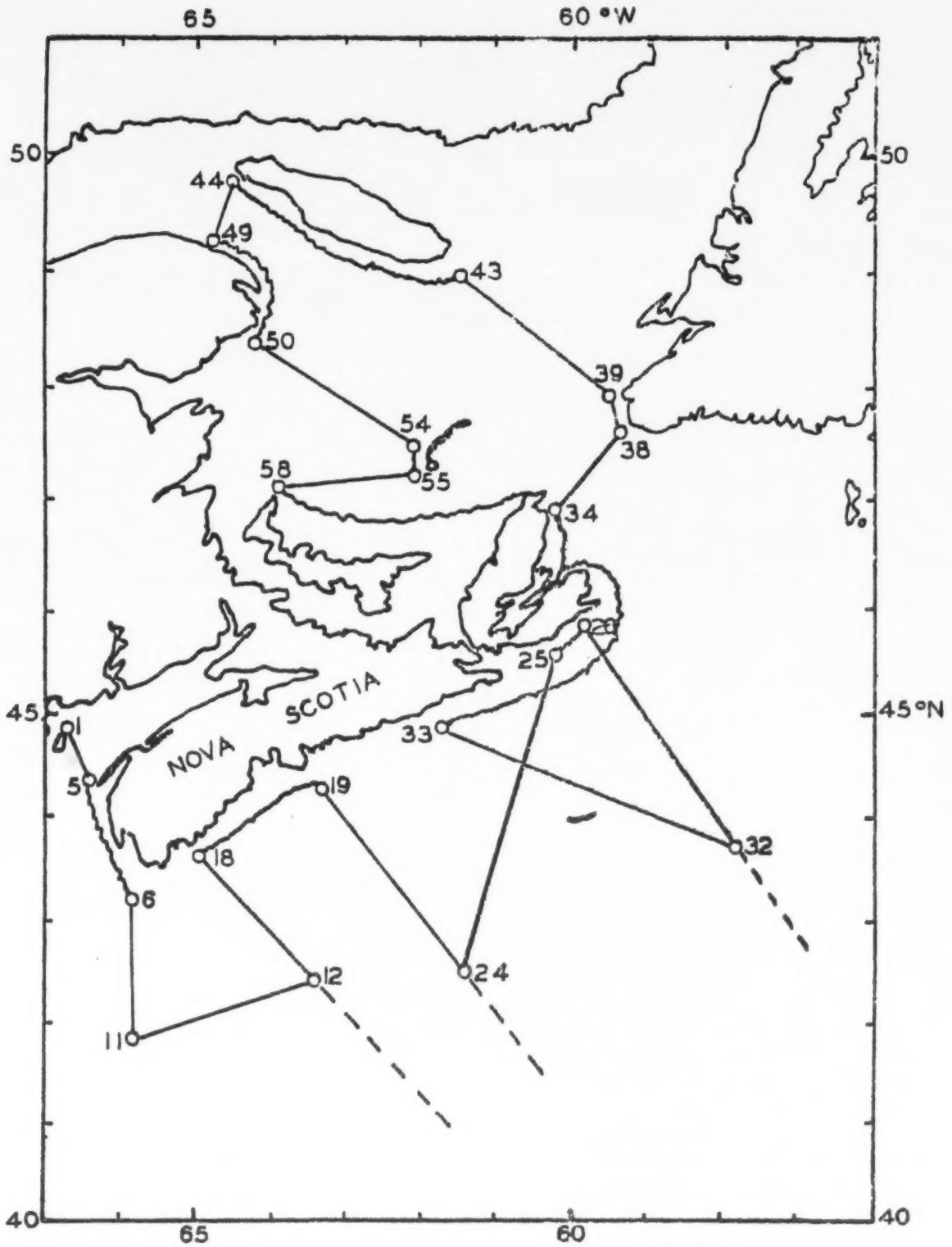
Dartmouth, N.S.
19 March 1964.



Position of Present and Requested Monitoring Sections and Areas.

Present Monitoring Services


FRB
(a) St. Andrews
Water properties
Coastal Stations
Twice daily temperatures
St. Andrews (surface)
Lurcher L.V. (surface and bottom)
Halifax Harbour (surface)
Port Borden (surface)
Entry Island (surface)
Sambro L.V. (BT cast - see DM&TS)
Offshore Stations
Monthly T and S at depth
Station 5 (Bay of Fundy)
Station 6 (Passamaquoddy)
Weekly (May to Oct. T & S at depth
Northumberland Strait (one station)
Twice monthly (May -- Oct.) T & S at depth
Northumberland Strait (one station)
Circulation
Drift releases
Daily releases
"Princess of Acadia" (2 points)
"Bluenose" (2 points)
"William Carson" (3 points)
"Lurcher L.V." (1 point)
"Sambro L.V." (1 point)
Monthly releases
Stations 5 and 6 (2 points)
Sea bed drifters
Daily releases (winter)
"William Carson" (4 points)
Plankton
Bay of Fundy (Stn. 5)
Passamaquoddy (Stn. 6)
Northumberland Strait
(b) AOC
Water properties
Halifax Section
Jan. Feb. March and quarterly
Cabot Strait
Varying frequency
(c) St. John's
Water properties
Monthly or better - Station 27 (off St. John's Harbour)
Sections annually or better (down to 1000 metres depth)
St. John's, Flemish Cap
Honavista Line and Triangle
Seal Island Line (southern Labrador)
Late July
Early August
Ca July 22-Aug. 5
St. John's - southeast Shoal
40 fathom line paralleling SW slope Grand Bank
Line at 275 m. along southern and western borders of Grand Bank and St. Pierre Bank
Ca Aug. 15-25
Stations, annually or better-St. Pierre Bank
Ca Aug. 15-25
DM&TS
Tides
Daily (Monday-Friday) synoptic surface temperature charts for entire N.W. Atlantic (Oceanographic Services for Defence)
Three times a week (Monday, Wednesday, Friday) Surface layer charts for entire N.W. Atlantic (O.S.D.)
DOT
Ice observations.
QUEBEC
Daily surface temperatures at Grande Riviere
Seasonal cruises
Bay of Chaleur
Fishing banks (Gulf of St. Lawrence)



Atlantic Oceanographic Group - Seasonal Surveys